C.P. No. 257
(17,859)
A.R.C. Technical Report

MINISTRY OF SUPPLY

AERONAUTICAL RESEARCH COUNCIL

CURRENT PAPERS

Saunders-Roe Princess Flying Boat LUN· G-A~~lun~~ Air and Water Handling Tests

LONDON . HER MAJESTY'S STATIONERY OFFICE

1956

SEVEN SHILLINGS NET

C.P. No. 257

M.A.E.E. Report No. F/185
(Saunders-Roe Report No. FT/15/0/24, Part 1)

January, 1955

MARINE AIRCRAFT EXPERIMENTAL ESTABLISHMENT

Saunders-Roe Princess Flying Boat G-ALUN
Air and Water Handling Tests

SUMMARY

The basic aerodynamic and hydrodynamic handling characteristics of the aircraft are satisfactory over the range of all operating conditions tested.

On the water, the aircraft is adequately stable on take-off and landing. The tests were made at weights between 225,000 lb and 315,000 lb, with C.G. positions between 29 per cent and 33 per cent S.M.C.

At the high weight in relatively rough water, fine spray entered the inboard propeller discs during the initial take-off run, causing slight bending of the tips. A stiffened propeller designed to overcome this trouble was fitted, but the flight trials programme was curtailed before tests could be made in adverse weather conditions. The spray characteristics, however, are considered to be satisfactory for both take-off and landing - the spray behaviour compares favourably with previous flying boats.

Under choppy conditions, slight hull pounding has been encountered. There was insufficient evidence to determine the conditions under which this would occur.

The limiting aft C.G. position is about 35 per cent S.M.C., this position being dictated by the high power, low airspeed conditions immediately after unstick. In high altitude cruising flight the aft C.G. limit is approximately 40 per cent S.M.C.

The aircraft is adequately controllable under asymmetric power conditions down to the stall, and the stalling behaviour is relatively good, there being adequate stall warning.

The existing simulated feel characteristics and control to control surface ratios require modifications in order to improve the feel of positive stability.

Greater flexibility of engine and propeller operating conditions on the water is desirable in order to improve the manoeuvring characteristics.

LIST OF CONTENTS/

LIST OF CONTENTS

1. INTRODUCTION.

2. DESCRIPTION OF AIRCRAFT.

2.1 General
2.2 Engines

3. CONDITION OF AIRCRAFT.

3.1 General
3.2 Loadings
3.3 Design Limitations
3.4 Powered Flying Controls

3.4.1 General
3.4.2 Changes in System During Tests

4. INSTRUMENTATION.

4.1 General
4.2 A.S.I. and Altimeter Static Pressure Error Corrections

5. SCOPE OF TESTS.

5.1 General Handling (Air)
5.2 Longitudinal Stability and Manoeuvrability
5.3 Lateral and Directional Stability and Control
5.4 Control with Asymmetric Power
5.5 Stalling Behaviour
5.6 General Water Handling and Stability

6. RESULTS OF TESTS

6.1 General Handling (Air)
6.2 Longitudinal Stability and Manoeuvrability

6.2.1 Static Stick Fixed Stability
6.2.2 Stick Fixed Manoeuvrability
6.2.3 Longitudinal Oscillations

6.3 Lateral and Directional Stability and Control

6.3.1 Rolling Performance
6.3.2 Sideslipping
6.3.3 Oscillatory Stability

6.4 Control with Asymmetric Power

6.4.1 Steady Flight at Low Airspeeds
6.4.2 Rolling Performance
6.4.3 Dynamic Behaviour at Low Airspeeds

6.5 Stalling Behaviour

6.6 General Water Handling Spray Characteristics and Stability

6.6.1 General Handling
6.6.2 Spray Characteristics
6.6.3 Water Stability

7. PILOT'S ASSESSMENT OF GENERAL HANDLING

7.1 General
7.2 Water Handling
7.3 Take-Off and Climb Away
7.4 Steady Flight at Low Airspeed

7.4.1 Power On
7.4.2 Power Off

7.5 Stalling Behaviour

7.5.1 Clean
7.5.2 Flaps and Floats Extended

7.6 Cruise and High Speed Flight

7.7 Approach and Landing

7.8 Cross Wind Take-Off and Landing

8. DISCUSSION OF QUANTITATIVE RESULTS

8.1 Longitudinal Stability and Maroeuvrability

8.1.1 Static Stick Fixed Stability
8.1.2 Stick Fixed Maneouvrability
8.1.3 Longitudinal Oscillations

8.2 Lateral and Directional Stability and Control

8.2.1 Rolling Performance
8.2.2 Sideslipping
8.2.3 Oscillatory Stability

8.3 Control with Asymmetric Power

8.3.1 Steady Flight at Low Airspeeds
8.3.2 Rolling Performance
8.3.3 Dynamic Behaviour at Low Airspeeds

8.4 Water Behaviour

8.4.1 Spray Characteristics
8.4.2 Take-Off Stability
8.4.3 Landing Stability

9. CONCLUSIONS

10. ACKNOWLEDGEMENTS

LIST OF SYMBOLS

LIST OF REFERENCES

LIST OF APPENDICES/

LIST OF APPENDICES

	Appendix No.
Aerodynamic Data	I
Hydrodynamic Data	II

LIST OF FIGURES

	Figure No.
G.A. of Aircraft	1
Photographs of Aircraft	2
Photograph of Handling Auto-Observer Panel	3
Elevator Response Curves	4
Elevator Load Curves	5
Aileron and Rudder Load Curves	6
Elevator Angles to Trim (Flaps and Floats Retractod)	7
Elevator Angles to Trim (Flaps and Floats Extended)	8
Static Stability Margin	9
Longitudinal Manoeuvrability	10
Longitudinal Oscillations	11
Rolling Performance	12
Sideslipping	13
Lateral Oscillations	14
Directional Oscillation	15
Control with Asymmetric Power	16
Simulated Engine Failure	17
Hull Trims during Take-Off	18
Hull Trims during Landing	19

1. INTRODUCTION

This report presents a summary of the handling, stability and control characteristics of the prototype Princess Flying Boat G-ALUN, as determined both in the air and on the water in the course of the flight development trials. From a number of aspects the account is not complete, as in the limited amount of flying which was done by the aircraft, subsequent to the initial development trials, priority was given to performance work to provide a basis for future development. Sufficient data of both a qualitative and quantitative nature, has however, been obtained to enable an assessment to be made of the overall behaviour both in the air and on the water. The aircraft completed a total of 96 hours 50 minutes flying time in 47 flights between August, 1952 and June, 1954.

2. DESCRIPTION OF AIRCRAFT

2.1 General

The Princess is a ten-engined high wing monoplane flying boat, a general arrangement drawing and photographs of which are given in Figures 1 and 2 respectively. The main aerodynamic and hydrodynamic data are given in Appendices 1 and 2.

The structure of the airframe is conventional, the hull being a figure-of-eight section superimposed on the V-shaped planing bottom, the main-step being faired in plan form and elevation. The intersection of the upper and lower lobes of the figure-of-eight forms the upper deck of the cabin, and the lower deck is formed by the intersection of the lower lobe with the planing bottom. The entire cabin above this lower deck is designed to be pressurised to a differential pressure of 8 p.s.i. The wing is constructed in five separate units consisting of the centre section which forms part of the hull structure, the inner wings, housing the ten engines distributed as one single unit and two coupled pairs per side, interspersed with the integral fuel tanks which have a total capacity of 14,500 gallons; and the outer sections which house the wing-tip floats and their retracting mechanism.

The tail unit, of conventional structure, is made up of that portion of the hull aft of the rear pressure bulkhead, and includes the single fin and rudder and dihedral tailplane and elevators.

2.2 Engines

The ten engines fitted for these trials are basically Bristol Proteus Mk. 600 propeller turbine engines, the Mk. number of 610 being given to a coupled pair. The engines are housed as six power units (numbered 1 to 6 commencing with the port outer) in the leading edges of the mainplanes, the left and right-hand engines of a coupled pair being referred to as A and B respectively. The single engines (1 and 6) are located in the outboard nacelles and each drives a four blade propeller which is reversible to facilitate manoeuvring on the water. The coupled engines (2, 3, 4 and 5) are housed in each centre and inboard nacelle and these drive eight blade contra-rotating propellers through a coupling gear-box and contra-rotating gear-box. The jet pipes for all the engines pass through the front and rear spars, the exhaust gases being discharged over the wing trailing edge.

3. CONDITION OF AIRCRAFT

3.1 General

Externally the airframe as tested was in a representative final form except that the junction between the wing tip and float, and the control surface gaps, were not as well sealed as could possibly be achieved. For the majority of the flying with the cabin unpressurised, an astro hatch for observational purposes was fitted in place of an escape hatch on the top of the hull practically in line with the main-plane trailing edge.

Internally, the aircraft was virtually unfurnished. The forward upper deck to the rear of the crew's compartment was allocated to flight test instrumentation and the entire length of the lower deck was occupied by water ballast tanks for loading and C.G. variation.

3.2 Loadings

The aircraft was flown over a range of weights of between 220,000 and 315,000 lb and C.G. positions of 27.5 to 35.5 per cent S.M.C. The handling, stability and control tests were in the main carried out at between 250,000 and 270,000 lb with C.G. positions between 28 and 32 per cent S.M.C.

3.3 Design Limitations

The following are the design operating limitations in force for the tests.

3.3.1 Airframe

Maximum take-off weight	320,000 lb
Normal landing weight	250,000 lb
Emergency landing weight	320,000 lb

C.G. Position, Take-Off and Landing

200,000 lb and below	25 per cent to 32 per cent S.M.C. (7.085 ft to 8.75 ft aft of C.G. datum). (15.12 ft to 17.12 ft above C.G. datum).
300,000 lb and above	27 per cent to 32 per cent S.M.C. (7.66 ft to 8.75 ft aft of C.G. datum). (15.12 ft to 17.12 ft above C.G. datum).

Limiting Level Flight and Diving Speeds

	Level Kts. (EAS)	Dive Kts. (EAS)
Altitude 0 - 10,000 ft	258	287
15,000 ft	248	-
20,000 ft	239	265
25,000 ft	225	-
30,000 ft	212	235

Wing Flap Extended Speed V_F

Deflection (degrees)	V_F Kts. (EAS)
45	136
30	156
15	165

Maximum floats operating speed, 145 knots (EAS)
Maximum speed with floats extended, 170 knots (EAS)

3.3.2/

3.3.2 Engines

Operating Limitations

R.P.M.	Compressor	Propellor Turbine Single	Propellor Turbine Coupled
Maximum for take-off (5 minute limit)	10,000	10,300	10,700
Maximum continuous	9,500	9,250	9,650
Ground idling	3,000/3,250	-	-
Minimum approach idling	6,500	-	-
Maximum for reverse pitch (5 minute limit)	10,000	10,300	Not applicable
Maximum for reverse pitch (10 minute limit)	9,500	9,250	Not applicable

Jet Pipe Temperature

Maximum for take-off - 5 minute limit	530°C
Maximum continuous	490°C

Maximum engine oil inlet temperature 80°C.

3.4 Powered Flying Controls

3.4.1 General

The powered flying controls are fully powered, irreversible and consist of conventional controls at the 1st and 2nd pilot's positions. These operate through shaft drives to the transmitter units from which flexible cables run to the appropriate power packs. The transmitter units incorporate an airspeed sensitive torsion bar hardening device superimposed on which is a variable trim mechanism.

Each power pack consists of a 120 volt D.C. electric motor continuously driving a variable flow hydraulic generator the output of which drives a hydraulic motor. The motor is connected through torsion shafts to screw jacks which are situated adjacent to and operate the appropriate control surface.

3.4.2 Changes in System During Tests

In the course of the initial flying it became apparent that the longitudinal response was over-sensitive owing to the power of the elevator. The stick movements and forces required to change speed and to manoeuvre were small (this is discussed in para. 7.1) and a modification, consisting of a differential gear-box, was introduced between the control system transmitter units and power packs. This considerably reduced the sensitivity of the elevator response over the normal working range, but was however achieved at the expense of unsatisfactory response characteristics outside the working range and with some loss of control travel.

The/

The gearbox was therefore modified to provide a compromise between these two systems, and this latter version is the one on which the aircraft handling assessment is based. The characteristics of all three systems in terms of stick-angle versus elevator angle are presented in Figure 4. The elevator hardener characteristics are shown in Figure 5 first in terms of stick angle, (this relationship being unaffected by the modifications introduced), and then in terms of elevator angle for the third elevator gearing. These characteristics have been taken in conjunction with the measurements of elevator movement per 'g' to indicate the order of the stick forces involved, as this gives a measure of stick free stability, and the ease or otherwise with which it may be possible to apply structurally dangerous loads to the airframe.

The rudder and aileron systems remained unchanged and the characteristics of these hardener systems are presented in Figure 6.

4. INSTRUMENTATION

4.1 General

The main flight trials instrumentation was distributed between 2 visual panels, 3 camera recording panels, and 2 galvanometer recorders. The 'handling' panel instruments were photographed by a 35 mm. cine camera capable of operation in single shots, or continuously up to a maximum speed of 4 frames per second. The items being recorded on this panel are listed below and a typical picture is shown in Figure 3.

Airspeed - normal and low reading	Time
Altitude	Time base
Acceleration - normal and longitudinal	Aircraft attitude
Air temperature	Angle of bank
Float position	Rate of pitch
Flap position	Rate of roll
Sideslip	Rate of yaw
Rudder angle	Aircraft heading
Elevator angle	Water contact
Aileron angle	

The engine conditions and fuel contents were recorded separately, readings being synchronised by the master time base operating a half second counter on all the recording panels.

4.2 A.S.I. and Altimeter Static Pressure Error Corrections

The static pressure error was determined by the aneroid method, the results and correction curves being presented in Reference 1.

5. SCOPE OF TESTS

5.1 General Handling (Air)

An overal qualitative assessment of the general handling behaviour of the aircraft was made over a range of flight operating conditions covering take-offs and landings, climbs, descents, and level flight from the stall to maximum permissible airspeed. This assessment was supplemented by automatic observer records to obtain control surface movements, etc.

5.2/

5.2 Longitudinal Stability and Manoeuvrability

Measurements of elevator angles to trim were made over a 4 per cent C.G. range, and from 105 - 260 knots I.A.S. with flaps and floats retracted at maximum continuous power (9,500 c.r.p.m.). Measurements with flaps and floats extended and also with flight idling and take-off power were made at one C.G. position only (32 per cent S.M.C.). Tests to cover a wider C.G. range under all configurations of power, flap setting, etc. were started but discontinued owing to readjustment of priorities, as discussed in the introduction.

Measurements were made of elevator angles in pull outs at various speeds with applied normal accelerations of up to 1.25 'g' at one loading condition only. These manoeuvrability and stability measurements were made generally at altitudes of up to 12,000 ft. At a higher altitude, 30,000 ft, the longitudinal oscillatory behaviour was recorded.

5.3 Lateral and Directional Stability and Control

Rates of roll were measured over a range of airspeeds from 115 to 240 knots I.A.S. at altitudes of between 2,000 and 10,000 ft.

In the same altitude range, commencing from trimmed speeds in steady level flight between 150 and 220 knots I.A.S., rudder and aileron angles to maintain steady angles of sideslip were measured, together with maximum rates of yaw on applying and taking off rudder.

At an altitude of 30,000 ft an investigation was made of the lateral and directional oscillatory behaviour.

5.4 Control with Asymmetric Power

At low altitude and airspeed, and at maximum power, records were made of control surface angles to trim with asymmetric power, and of rates of roll into and away from the dead engines. The dynamic behaviour subsequent to engine failure at low airspeeds, 110 - 130 knots, was also investigated.

5.5 Stalling Behaviour

Records of the stalling behaviour in steady straight flight were made with flaps and floats both extended and retracted. These tests were made at an altitude of approximately 10,000 ft and at low power, approximately 7,500 c.r.p.m.

5.6 General Water Handling and Stability

A general assessment of the water handling characteristics was made, together with records of take-offs and landings at various fixed elevator settings at all-up weights of between 225,000 and 300,000 lb, and a C.G. position of 29.5 per cent S.M.C. Taxying speeds and turning behaviour on the water were investigated. The sea conditions varied from glassy calm to 4 ft seas with a 20 to 1 length to height ratio.

Out of wind take-offs were made with cross-wind components of up to 12 knots in order to assess the handling characteristics in this condition together with the effects on performance.

6./

6. RESULTS OF TESTS

6.1 General Handling (Air)

The general handling qualities under all conditions of flight are discussed separately in paragraph 7.

6.2 Longitudinal Stability and Manoeuvrability

6.2.1 Static Stick Fixed Stability

The results of elevator angle to trim measurements are presented as η vs. C_R in Figures 7 and 8. Figure 7 shows stability with the flaps and floats retracted at various power settings, with the C.G. at 32 per cent S.M.C., and at one power setting with the C.G. at 28 per cent S.M.C. In Figure 8, the results with flaps and floats extended are presented for a C.G. position of 32 per cent S.M.C. at two power settings. For comparison, the stability characteristics with flaps and floats retracted at the same power settings and C.G. position are also included on this graph.

On Figure 9, the stick fixed static margins are presented for the two C.G. positions (28 and 32 per cent S.M.C.) at maximum continuous power. For reference purposes, on Figure 9 the variation of propeller thrust coefficient (T_c) with C_R has been shown for the take-off and maximum continuous power settings appropriate to the elevator trim measurements.

6.2.2 Stick Fixed Manoeuvrability

In Figure 10 the elevator angles to trim and to apply 0.5 and 1.0 g normal acceleration are plotted as η vs. C_R for a C.G. position of 30.5 per cent S.M.C. at an all-up weight of 270,000 lb with maximum continuous power at 10,000 ft. These results have then been interpreted in terms of elevator movement per 'g' and force per 'g' (based on the elevator load curves of Figure 5) and are plotted in Figure 10 as η per 'g' and stick force per 'g' against C_R for 0.5 and 1.0 g applied accelerations.

6.2.3 Longitudinal Oscillations

Time history plots of the aircraft behaviour subsequent to sharp elevator displacement in both directions are shown in Figure 11. These results are for level flight at 30,000 ft with maximum continuous power and a mid C.G. position.

6.3 Lateral and Directional Stability and Control

6.3.1 Rolling Performance

The results of the rate of roll measurements with flaps and floats retracted are plotted in Figure 12 and are interpreted so as to present rate of roll for aileron angles of between 0 to 20 degrees and forward speeds of 100 to 240 knots E.A.S. Shown also on this figure is the design limiting aileron angle over the speed range as governed by the maximum hinge moment (power pack blow off operating) and the low speed rolling requirement $pb/2v = 0.07$ radians.

6.3.2 Sideslipping

The sideslipping behaviour with flaps and floats retracted, appropriate to an altitude of 5,000 ft and airspeeds in excess of 150 knots I.A.S. is shown in Figure 13.

In/

In this figure the steady angle of sideslip is plotted against rudder and aileron angle. The maximum rate of yaw attained on application of rudder before steady sideslip occurs is plotted against applied rudder angle, and the maximum restoring rate of yaw on returning the rudder to neutral when in a condition of steady sideslip is plotted against the sideslip angle. The power conditions are appropriate to that required for level flight at each speed.

6.3.3 Oscillatory Stability

In Figures 14 and 15, time histories are presented of the behaviour of the aircraft subsequent to sharp application of the aileron with rudder held fixed and rudder with aileron held fixed. These histories are appropriate to level flight at 30,000 ft, at maximum continuous power.

6.4 Control with Asymmetric Power

6.4.1 Steady Flight at Low Airspeeds

The rudder and aileron angles to maintain steady straight flight at low altitude with wings level, under take-off asymmetric power conditions with flaps and floats retracted, are plotted against indicated airspeed in Figure 16.

6.4.2 Rolling Performance

The results of measurements of aileron effectiveness under asymmetric power conditions are also plotted in Figure 16 in terms of rate of roll for various aileron angles (into and away from the dead engines) against indicated airspeed.

6.4.3 Dynamic Behaviour at Low Airspeeds

A time history of behaviour subsequent to a simulated engine failure of engines 1, 2A and 2B simultaneously at 110 knots I.A.S. altitude of 2,300 ft with a corrective action time delay of approximately 5 seconds is presented in Figure 17.

6.5 Stalling Behaviour

An assessment of the stalling behaviour with flaps and floats both extended and retracted based on qualitative impressions and quantitative results is presented in paragraph 7.

6.6 General Water Handling, Spray Characteristics and Stability

6.6.1 General Handling

A general handling assessment covering take-offs into and across wind, landings, taxying and manoeuvring on the water is given in paragraph 7.

6.6.2 Spray Characteristics

The spray characteristics are discussed in paragraph 8.4.1.

6.6.3 Water Stability

Hull trim attitudes during take-offs and landings are plotted in Figures 18 and 19 and show the effect of weight, elevator angle, flap setting and power at a fixed C.G. position. (29.5 per cent S.M.C.).

7./

7. PILOT'S ASSESSMENT OF GENERAL HANDLING

7.1 General

In an aircraft with a fully powered irreversible control system, control-free characteristics cannot be assessed in the hitherto accepted sense; they do exist however but are purely a function of the artificial feel generator (hardener). The forces involved are quite arbitrary but they indirectly define the ease and safety with which the aircraft can be flown. Alteration of hardener characteristics can from force feel alone, completely alter the apparent stability characteristics to the pilot for a given manoeuvre though the control angle to trim remains unaltered.

Qualitatively the true longitudinal characteristics - and to a lesser degree both the lateral and directional ones as well - were masked by backlash in the control circuit. The power of the aircraft controls was such that relatively small control angles were needed and backlash, though small in relation to the total travel, was large in relation to the control demand. The result of backlash superimposed on an unsatisfactory stick to control surface gear ratio has been to give an impression at times of apparent instability which has been caused by searching and over-sensitivity.

Modification to the stick to elevator gear ratio produced improved, but not entirely acceptable, feel characteristics, although the quantitative results were satisfactory. (See paragraph 8.1). It would appear that the undesirable characteristics produced at the pilot's control could be eliminated by mechanical means.

7.2 Water Handling

Engine conditions for taxying were dictated partly by electrical generating requirements and partly by the fact that the pilot had no control of throttles until flight idling c.r.p.m. were reached. With 24 volt generation on engines 2 and 5 only, and a restriction placed on running a half-coupled engine without its companion for more than 5 minutes, it was normal to have engines 2a, 2b, 5a and 5b under pilot control at flight idling c.r.p.m. and propellers in superfine pitch ($-5\frac{1}{2}$ degrees), immediately after slipping moorings. The outboard units with reversible propellers were also kept at flight idling c.r.p.m. which was the minimum for the reversing operation. Forward speed with 6 engines at flight idling c.r.p.m. was approximately 8 - 10 knots and higher than desirable in restricted waters, but it could be controlled down to zero by use of the reversing propellers. These features introduced difficulties for mooring operations which could not be improved to any extent by the use of drogues. This aspect is covered in Reference 2. In near calm conditions a turning radius of about $1\frac{1}{2}$ - 2 spans could be obtained, with six units running at flight idling c.r.p.m. if the manoeuvre commenced from zero speed, and using full thrust from an outboard engine plus a small percentage from the adjoining coupled unit. In winds of 15 knots or more, when turning across or through 180 degrees downwind, larger power increments were needed from the coupled units to keep a reasonable turning circle. The wing tip float buoyancy was adequate for all water manoeuvres, there being no tendency for either float to dig in.

Directional forces opposing yawing motions increased noticeably with forward speed; when all engines were running at flight idling c.r.p.m. the turning radius was increased by the relatively higher taxying speed. In this configuration the use of full reverse thrust from one engine would bring the turning radius down to the equivalent of that obtained with six units at flight idling c.r.p.m. and without reverse thrust.

Weathercocking/

Weathercocking characteristics appeared to be normal, having regard to the high inertia of such a large aircraft. At zero or near zero speeds in running tides the component resulting from combined air and water drag appeared to be influenced more by the former than might have been expected. When taxying dead into wind minor corrections for course could be made with the rudder, otherwise of course power steering was more efficient.

7.3 Take-Offs and Climb-Away

The artificial feel forces selected for the aircraft were low enough to enable a take-off run to be made with only one hand on the control column and without any undue effort. Foot forces were proportionately low. The six throttles, which had a combined operating load of 12 - 15 lb could be handled with ease. Isolation of individual throttles to correct incipient yaw at the start of the run, could be done without undue concentration.

When travelling into wind, or in zero wind, if all throttles were opened quickly no yaw normally resulted. No hooking tendencies showed up at any time and divergencies due to small cross-wind gust components or unequal power applications were slow to materialise and were easily corrected. The rudder began to become effective at about 30 knots air speed. .

From commencement of take-off to hump trim, which was relatively low at about 10 degrees (see paragraph 8.4.1) the transition was gentle and almost unnoticeable to the pilot. Similarly the post-hump pitch forward to the planing conditions was gentle the resulting oscillation being slow to materialise and this could easily be damped by upward elevator movement after 2 or 3 cycles. Application of coarse negative elevator as the initial nose-down moment occurred would normally prevent any oscillation at all. Flap settings of up to 50 per cent were used on take-offs and the nose-down trim due to ground effect made no abnormal demand on the elevator.

With full aileron application the down wing float could be brought clear of the water at about hump speed; with a normal single-handed control movement of about 70 to 75 per cent travel an increase of roughly 10 knots in the clearance speed would occur.

A C.G. range of 29 to 33 per cent S.M.C. was covered during tests; water conditions varied from glassy calm to the case of a 4 ft sea with 20:1 length to height ratio. With correct and normal positioning of elevators no pitching instability showed up at any condition and there appeared to be adequate elevator power available for a forward extension of the C.G. Rough water take-offs could not be attempted without risk of bending the tips of the inboard propellers, damage to them having been sustained in heavy chops (see paragraph 8.4.1). The only unusual feature of chop conditions was that of slight hull pounding but there was insufficient evidence to determine the conditions under which this could occur since it was experienced at weights between 240,000 and 310,000 lb. and at speeds between 40 - 70 knots; the height and length ratio of the chop also varied from run to run.

At the aftermost C.G. position tested (33 per cent S.M.C.) the aircraft appeared neutrally stable longitudinally between unstick and approximately 140 knots - at full power. The stabilising effect due to ground effect was a powerful one and it completely disappeared at about 50 ft, but when the aircraft attained approximately 140 knots the increasing stability due to acceleration more than compensated for the decrease of the stabilising ground effect. At the forward C.G. position, stick forces could be comfortably maintained up to steady climb speed either in or out of the ground cushion without retracting the flaps. Float retraction had

no/

no apparent effect on longitudinal stability though a mild jolt could be felt as each float reached its locked up position. Both the nose down moment due to flap retraction and the resultant sink if uncorrected, were mild and innocuous, flap movement was slow and the speed of retraction ideal.

Lateral and directional stability were good on unstick and climb away; there was no lateral change of trim as floats were retracted although they were not synchronised.

7.4 Steady Flight at Low Airspeed

7.4.1 Power On

At maximum continuous power, outside the ground cushion and with flaps up there was a feeling of slight longitudinal instability at any C.G. position, and speeds below 140 knots I.A.S. Likewise, in steady climb conditions at any of the C.G. positions tested there seemed to be only just neutral longitudinal stability between 155 knots, I.A.S. which was initial climbing speed, and 145 knots which gave best climb at higher altitudes.

Laterally and directionally the stability was satisfactory in the climbing airspeed range but the comments on control to control surface gear ratio apply to rudder and aileron as well as elevator. Strong adverse aileron yaw characteristics existed (see paragraph 8.2.3) even at low speeds and it was not possible to monitor the aircraft directionally with any accuracy by aileron alone, though the amount of compensating rudder was small.

7.4.2 Power Off (Flight Idling c.r.p.m.)

From the speed at which flaps could be lowered (165 knots) down to a circuit speed of about 140 knots, the stability characteristics about all axes were good and control responses excellent. If flaps were lowered at the maximum permissible speeds for any given setting the change of trim was gentle, with small stick movements and forces needed to compensate for it.

Lowering of floats had no apparent effect on either lateral trim or stability, though they unlocked and lowered asymmetrically.

7.5 Stalling Behaviour

Only brief stalling tests have been made at two aircraft weights of 285,000 lb and 270,000 lb, C.G. position 29.5 per cent S.M.C., with all engines operating at flight idling c.r.p.m. and in two aircraft configurations.

(a) Clean (flaps and floats retracted).
(b) Flaps and floats extended.

7.5.1. Clean

With the aircraft in straight steady flight, speed was reduced at a rate of about half a knot per second. An actual stall did not occur in this clean condition, there being only a series of slow large amplitude pitching motions and recoveries, at an airspeed of about 101 knots I.A.S. Buffeting set in at approximately seven knots above this pitching speed, becoming heavy at the minimum speed. Lateral control could be maintained during the pitching, and easing the stick forward brought instant recovery.

7.5.2 Flaps and Floats Extended

Buffeting is less violent with flaps and floats down and again commences at about seven knots above the actual stall. About 80 per cent of maximum up elevator was required to produce the stall at about 92 knots I.A.S. which resulted in a fairly steep nose down attitude. Lateral control could be maintained to within about 2 knots of the fall away. Two stalls were made without wing drop but either port or starboard wing could drop; lateral trim and aileron position at the actual stall probably dictates the final attitude but insufficient tests were made to say conclusively the determining factor. There was no spinning tendency and aileron power was adequate to bring the wing up immediately speed increased with the nose drop.

For its size and wing loading the stall characteristics of this aircraft cannot be said to be vicious; adequate warning is provided by the buffeting.

7.6 Cruise and High Speed Flight

The majority of flying took place below 15,000 ft, and, at the aftermost C.G. position of 33 per cent S.M.C., longitudinal stick fixed stability was positive from 165 knots I.A.S. to the maximum diving speed. The stick force per 'g' was considered satisfactory in a 2g manoeuvre (see paragraph 8.1.2) after the stick to surface movement ratio had been modified; this aspect is covered in paragraph 3.4.2 and in detail in Reference 2, insofar as it relates to the Power Control Systems.

At 30,000 ft with a C.G. position of approximately 29.5 per cent S.M.C., the longitudinal stability felt about neutral though elevator trim measurements show it to be positive (see paragraph 8.1.1). With reduced damping at height, the destabilising effect caused by the backlash and over-sensitivity of control was similar in the cruise to that experienced in the climb. The modification to the elevator control run which decreased the stick to surface movement ratio was not incorporated for the high altitude flights, but judging from the results at low altitude the new ratio would have made handling quite satisfactory at high altitude also.

The tendency to overcorrect about the lateral and directional axes was also more noticeable at high altitude but the overall handling characteristics at 30,000 ft were satisfactory.

7.7 Approach and Landing

Though the intended operational procedure was to cut one half of each coupled engine during the let-down, this method was precluded by the restriction against operating a half coupled unit alone.

Landing weights on test flights were usually well above an operational landing weight and it was customary to maintain ten engines at flight idling c.r.p.m. or above during the approach, since at the relatively low power of the Proteus II a baulked landing could not always be safely made on six engines. Nevertheless, final approaches and landings were made with various combinations of flight and ground idling r.p.m. from coupled engines, as well as with circumstantial engine-out cases.

With the propellers at the flight fine pitch setting, and with all engines fully throttled, the idling thrust was relatively high, and an approach at 1.25 times touch-down speed produced a very flat flight path. Despite the coarsening of attitude on flare-out as the influence of ground effect increased, the deceleration remained slow. Reducing the four inboard engines to ground idling c.r.p.m. during the flare-out was of some assistance, and this on occasion was done at 100 - 150 ft in which case the pilot was then committed to the landing and an overshoot could only be made if/

if flaps were first retracted by about 50 per cent. Measured rates of descent showed that there was as little as 100 f.p.m. increase when four half-units of coupled engines were brought to ground idling c.r.p.m. as compared to the condition with ten engines at flight idling c.r.p.m. Operationally a higher flap and/or propeller drag would be desirable in order to obtain a controlled flight path of reasonable angle.

Quantitative landing measurements were made at a C.G. position of 29.5 per cent S.M.C. although on one test a landing was made at 27.5 per cent S.M.C. Adequate negative elevator was then available and would have permitted operation at a more forward C.G. position. The aftermost C.G. position at which landings were made was 32.5 per cent S.M.C., the aircraft being longitudinally stable right down to touch-down speed. Flap position at approach power conditions did not materially alter the longitudinal characteristics. Landings have been made with flap settings from zero to fully down, the amount of elevator required during flare-out and touch down for a given contact attitude being proportionate to flap angle. Ground effect was progressively noticeable from a height of about 10 feet downwards and was greatly influenced by flap angle.

Touch-down speed was generally 95 - 100 knots I.A.S. and was not noticeably affected by the last 25 per cent of flap increment, but full flap was considered essential for drag reasons. The lower limit of water stability on landing has been crossed on several occasions - the hull datum being about 3 degrees, the resultant oscillation was gentle and no skipping occurred. It could be quickly damped by increasing the attitude. The upper limit has never been reached at any touch-down attitude attained - the maximum being 8 degrees. The maximum attitude during deceleration irrespective of C.G. position was about 12 degrees, and by the application of power at an appropriate time it could be reduced.

7.8 Cross-Wind Behaviour on the Water

Flight tests ended before any conclusion could be drawn as to cross-wind handling characteristics. The only quantitative test was made in a 12 knot cross-wind component at an all-up weight of 262,000 lb with a view to determining a suitable technique and to assess the effects on performance. The limiting cross-wind component would, in the first instance, depend on the loss in performance during acceleration to and over the hump, due to the throttling of down-wind engines.

8. DISCUSSION OF QUANTITATIVE RESULTS

8.1 Longitudinal Stability and Manoeuvrability

8.1.1 Static Stick Fixed Stability

The basic requirements of longitudinal stability are for positive stability stick free under all flight conditions, and for a margin of stick-free over stick-fixed stability not greater than 5 per cent. This normally permits of operations at C.G. positions which give a slightly negative stick-fixed static margin.

Whilst the aircraft has no stick-free stability as such, the hardener system governs the stick forces required to change speed (see paragraph 7.1), and these will become zero when the aircraft is neutrally stable stick fixed and be reversed when it becomes unstable. Any feeling of instability will, generally, be proportional to the degree to which the system produces a feel of stick-free stability. The criterion therefore for longitudinal stability in this case is for positive stability stick fixed under all flight conditions.

The/

The systematic measurements of elevator angles to trim which have been made are shown in Figures 7 and 8. In Figure 7 which is for the aircraft in a clean configuration, i.e., floats and flaps retracted, the effect on the elevator angle to trim of the power setting at one C.G. position (32 per cent S.M.C.) and of C.G. position at one power setting, (9,500 c.r.p.m.) is clearly shown. From these latter measurements the stick fixed static stability margins (K_n) have been determined and are presented in Figure 9, although the C.G. range covered (4 per cent S.M.C.) is smaller than is generally considered desirable for accurate determination of the static margins.

The measurements with flaps and floats extended (Figure 8) were made at one C.G. position only (32 per cent S.M.C.) making any quantitative assessment of the stability margin impossible. However, a comparison of the trim curve slopes for this and the clean case indicates that with the flaps and floats down the aircraft is probably as stable at 10,000 c.r.p.m. at low airspeeds, as with flaps and floats up at 9,500 c.r.p.m. With flight idling power settings the curves in both configurations suggest adequate positive stability. With flaps and floats retracted the static margins indicate that with maximum continuous power the aircraft is neutrally stable at a C_R of 1.3 to 1.4 at a C.G. position of 32 per cent S.M.C., the stability rapidly becoming positive with increase in speed. The slopes of the elevator trim curves for maximum power with flaps and floats extended and retracted suggest that at the same C.G. position neutral stability occurs at C_R values of about 1.6 and 1.1 respectively.

For the power on cases at lower C_R values where the aircraft is stable, the elevator movements to change speed are small, the corresponding stick movements and forces therefore being small also. For example, at the aft C.G. position with 9,500 c.r.p.m. the elevator movement to increase speed from 120 to 140 knots E.A.S. at 250,000 lb (C_R 1.0 to 0.75) is about 0.6 degrees and the corresponding angular stick movement is about the same, the linear movement at the top of the stick being of the order of 0.35 in. This small movement is within the backlash of the control circuit (see paragraph 2.3 and Figure 5) so that the forces involved would be negligible giving an impression of near neutral stability. Reference to Figure 9 shows that over the range considered the stick-fixed static margin is in fact quite positive, increasing from 8 per cent to 16 per cent. Any reduction in the stick-fixed static margin, either by decrease in speed or increase in power would of course aggravate the impression of neutral stability and it is for this reason that the investigations into stick to elevator gearing were made.

These same remarks apply to the stability at high altitude where brief checks have indicated no deterioration of stick-fixed stability, although the decreased speed (C_R) range available in level flight would tend to give an impression of less stability than at lower altitudes, for the same reasons as those discussed above.

Bearing in mind that the measurements are not sufficiently adequate to confirm fully all of these indications, it is clear from the qualitative and quantitative assessment that the least stable case is that of low speed, at full power with flaps and floats retracted, which is appropriate to the initial climb away after unstick. Under flight conditions of normal climb, high altitude cruise, descent and approach conditions, positive stability would probably be maintained with C.G. positions of about 40 per cent S.M.C.

The furthest aft position at which take-offs have been made is 33 per cent S.M.C. and any lack of longitudinal stability has produced no undesirable handling characteristics. A flap setting of 20 per cent is normally used for take-off and the measured results indicate that flap has no appreciable stabilising effect. This fact, together with the probable stabilising influence which the ground effect has on an aircraft of the

size/

size of the Princess (see paragraph 7.3), would indicate that a higher degree of stability exists after take-off than the full power measurements in free air with the flaps up, presented in Figure 7, would suggest. The limiting aft C.G. position for the take-off and initial climb would be about 35 per cent S.M.C. at which position, with the existing hardener system, the aircraft would not feel any less stable than with the C.G. at 33 per cent S.M.C. The desirable operating technique would be to accelerate rapidly to 140 knots, and then to reduce power before raising the flaps, hence climbing away in conditions of adequate positive stability. The baulked landing case has then to be considered, but at a reduced fuel load the C.G. would be further forward than in the take-off case and if the flaps were raised to the take-off setting no instability would occur.

8.1.2 Stick-Fixed Manoeuvrability

The measurements of the elevator angles to manoeuvre (Figure 10) indicate satisfactory characteristics at the weight (270,000 lb) and C.G. position (31 per cent S.M.C.) tested. The elevator movement per 'g' is positive and reasonably large, the lower values based on 0.5 'g' applied as opposed to those with 1.0 'g' applied, might suggest that the elevator power per degree movement of the surface is greater at the small elevator angles.

The percentage of the total elevator movement (as limited by the design maximum hinge moment) required to produce 1.0 'g' is approximately 47 per cent for airspeeds between 150 and 250 knots.

The maximum applied normal acceleration would therefore be of the order of 2.0 'g' (3.0 'g' indicated). The ease with which the elevator angle can be applied is a function of the hardener characteristics, and from these the stick force per 'g' has been derived and is included in Figure 10. The mean force per 'g' over the speed range (150 - 250 knots) is 35 lb with 1.0 'g' applied, which is approximately 75 per cent of the force required to produce the maximum available elevator angle.

8.1.3 Longitudinal Oscillations

A brief investigation of the longitudinal short period oscillatory stability has been made at an altitude of 30,000 ft. There is no short period oscillation for the control free case, the control centring characteristics being only a function of the hardener. The aircraft behaviour subsequent to a sharp out of trim elevator deflection immediately returned to the trim position, was heavily damped, typical time histories for both a positive and negative elevator deflection being shown in Figure 11, these being appropriate to an aircraft weight of 240,000 lb and C.G. position of 29.2 per cent S.M.C. It will be seen that the pitching motion is damped out in 1 cycle in about 4 seconds. Other than the fact that the power of the elevator has given rise to an apparent increase in sensitivity at the reduced speed range at high altitude (paragraph 7.6 and 8.1.1) there have been no signs of any long period oscillation.

8.2 Lateral and Directional Stability and Control

8.2.1 Rolling Performance

The low altitude (up to 10,000 ft) rolling performance (Figure 12) has been derived from a series of measurements over a wide range of airspeeds and aileron applications. This data which is related to flaps and floats retracted, (no measurements having been made with them extended) indicates adequate aileron power at all airspeeds.

The/

The basic low-speed rolling requirement is that at 1.3 times the stalling speed, the helical angle should not be less than 0.7 radians. This helical angle is plotted on Figure 12 and shows that at 1.3 V_S (130 knots), the requirement is met with 14 degrees of aileron which is 70 per cent of the total movement available at that speed. The associated control force simulated by the hardener is 23 lb.

The damping-in roll was good in all of the measured cases, a steady rate of roll being established within one second of the aileron movement ceasing. Other aspects are discussed in paragraph 8.2.3.

8.2.2 Sideslipping

The steady sideslip behaviour and recovery defines the static directional stability in terms of yawing moment due to sideslip (n_v) and lateral stability in terms of rolling moment due to sideslip (l_v).

The results presented in Figure 13 show rudder and aileron angles to maintain steady sideslip, together with maximum induced and restoring rates of yaw for symmetric power flaps and floats retracted. Insufficient measurements are available to detect any significant variation with airspeed or direction of sideslip, and therefore single lines have been drawn through the points in each case.

The rudder is amply effective, at small angles, angle of side-slip per degree of rudder application being 1.2, decreasing with increasing angle of slip to approximately 0.5 at 8 degrees. The amount of sideslip which can be applied at any airspeed is a function of the rudder movement available for the maximum hinge moment, and is of the order of 6 degrees at 250 knots, 8.5 degrees at 200 knots, and, extrapolating, would be a maximum of about 15 degrees at the limiting rudder angle of 30 degrees at 120 knots E.A.S. The estimated fin stalling angle is 24 degrees and therefore there would appear to be a good margin to prevent fin stalling under both steady and dynamic conditions. There is no rudder aerodynamic over-balance in the normal sense, any such tendency would only be shown by relating power pack output pressure to sideslip, or by the ability to obtain greater rudder angles than the design maximum, and no such measurements were made.

The effectiveness of the rudder in producing yaw is shown as the maximum rate of yaw attained against rudder angle and is 0.33 degrees per second per degree of rudder application. In general, the maximum rate is attained about 2 seconds after the rudder has ceased moving and becomes zero (steady sideslip) after 5 seconds. The restoring rate of yaw on returning rudder and ailerons to neutral is 0.29 degrees per second per degree of sideslip and is indicative of positive directional stability.

The aileron angle required to maintain steady sideslip is against rudder, i.e., to prevent rolling away from the direction of side-slip, and is of the order of 0.35 degrees per degree of sideslip, and indicates positive lateral stability. A measure of the order of the rolling moment due to the sideslip may be obtained by relating the aileron angle to trim, to the rate of roll produced by application of the same surface angle in steady flight. For example, 2 degrees of aileron is required at about 6 degrees of sideslip, and referring to Figure 12 this would produce a rate of roll of 2 degrees per second at 180 knots E.A.S. in steady flight.

The dynamic behaviour following sharp applications of aileron and rudder is discussed in the following paragraph. It is relevant to note here that in the course of the sideslips no significant change in longitudinal trim was observed.

8.2.3 Oscillatory Stability

The dynamic lateral and directional stability has been examined only briefly in level cruising flight at 30,000 ft, but the time histories obtained (Figures 14 and 15) are interesting.

Referring to Figure 14, which is for a sharp deflection of aileron through 13 degrees, rapidly returned to neutral with rudder held fixed, the adverse aileron yaw is apparent. In the roll to starboard the higher induced drag of the down-going port aileron has produced a yaw to port giving rise to sideslip to starboard. When the aileron is taken off the aircraft commences to roll back, and the restoring yawing moment to starboard takes effect to reduce the sideslip which results in a rolling moment to starboard; this in turn temporarily cancels the restoring rolling moment to port until the angle of sideslip which has overswung is reduced again by yawing to port, producing a rolling moment which now assists the return to a wing level state. This behaviour is well damped and indicates good oscillatory stability characteristics.

Figure 15 shows the effect of a sharp rudder application of 8 degrees to starboard with ailerons held fixed. The resulting rate of yaw produces a sideslip to port, the combined effect of which is to produce roll to starboard. Restoring forces rapidly take effect, the resulting motion being well damped.

Each of the motions discussed above was repeated in the opposite directions, the behaviour being substantially the same. For this flight condition at least, it can be said that lateral and directional oscillatory stability characteristics are satisfactory, and taken in the light of the rolling and sideslip behaviour suggests that the overall lateral and directional control is good.

8.3 Control with Asymmetric Power

8.3.1 Steady Straight Flight at Low Airspeeds

The rudder and aileron angles to trim shown in Figure 16 were measured with a degree of asymmetry representative of a projected development of the Princess with six as opposed to ten engines. These measurements were made prior to investigating the dynamic behaviour following sudden simulated engine failure, and represented a minimum control speed condition, flaps and floats retracted. At 110 knots I.A.S. (approximately 1.1 times the stalling speed) steady straight flight could be maintained with wings level with rudder and aileron angles of 17 degrees and 5 degrees respectively, the rudder angle being 57 per cent of the total available and the hardener pedal load being about 70 lb. Extrapolation indicates that the asymmetry could still be held down to the stall (100 knots I.A.S.) at a rudder angle of 20 degrees.

8.3.2 Rolling Performance

The rolling performance with asymmetric power which is also shown in Figure 16 gives a measure of the static rolling moment due to the asymmetry. The rate of roll with zero aileron is about 2 degrees per second into the dead engines, and the measurements show the ability to roll into and away from the dead engines. The slope of the rate of roll aileron deflection relationship at any speed is somewhat less into the dead engines than away from them, this effect probably being attributable to rolling moment due to the rudder. The rudder angle being deflected to starboard to maintain steady trim (paragraph 8.3.1) contributes to the roll to port.

It is interesting to note that the basic low speed rolling requirement that the helical angle should be not less than 0.07 radians at 1.3 times the stalling speed (paragraph 8.2.1) can still be met, rolling against the dead engines. At 130 knots the rate of roll appropriate to the requirement is 8 degrees per second and reference to Figure 16 shows that this is just attained with 20 degrees of aileron, which is the maximum available at this airspeed.

8.3.3 Dynamic Behaviour at Low Airspeeds

The dynamic behaviour following simulated engine failure was investigated at various airspeeds with corrective action time delays of 2 and 5 seconds. For the sake of simplicity in simulating sudden engine failure, engines 1, 2A and 2B were all cut to ground idling conditions, thereby introducing a slightly higher degree of asymmetry than in the static case (paragraph 8.3.1 and 2). A time history of the worst case tested (engines cut at 110 knots I.A.S. and corrective action time delay 5 seconds), is presented in Figure 17. This shows that prior to corrective action being taken the aircraft has banked (dead engines down) through 10 degrees, the heading has changed 5 degrees to port and there are 2 degrees of sideslip to starboard. The application of 20 - 25 degrees of rudder and aileron at this condition has the effect of arresting the increase in rate of yaw (stopping the acceleration in yaw) and reducing the rate of roll. These rates are not shown in Figure 17 but the effects are immediately apparent as at 9 seconds on the time history (2 seconds after the control application) the angle of bank is decreasing and the angle of sideslip and heading, while still increasing, are now doing so at a steady rate. At 13 seconds with 25 degrees of rudder (85 per cent) and hardener pedal force 80 lb the rate of yaw decreases, becoming zero at 15 seconds, at which point the change of heading and sideslip reach the maximum values attained. The change of heading is 20 degrees, angle of sideslip 9 degrees, and the aileron angle is being gradually returned to neutral, the angle of bank being 8 degrees to starboard (dead engines up). For the next 10 seconds (to 25 seconds) the aircraft is yawing to starboard reducing the sideslip to zero and the heading to 6 degrees from the original, and the angle of bank to starboard is decreasing. During this period the speed had been permitted to increase to 120 knots with a slight loss in altitude, but at 25 seconds the speed is again being reduced. At 30 seconds, (i.e., 26 seconds after engine cut, 21 seconds after corrective action) a reasonably steady flight condition has been attained at the original airspeed. The rudder angle has been reduced to 19 degrees and aileron to 7 degrees (17 and 5 degrees respectively for steady trim at 110 knots - Figure 16). The heading is 4 degrees from the original sideslip, 2 degrees to starboard (both decreasing) and the aircraft is banked 4 degrees to port.

The indications from this, together with the steady trim and rolling characteristics, are that the aircraft is adequately controllable down to 110 knots I.A.S. with a failure of the three outermost engines on one side, and a corrective action time delay of 5 seconds, which is a severe case with the aircraft in its present form. The minimum control speed for failure of a mid-coupled unit would almost certainly be coincident with the stalling speed. Whilst this is indicative of the adequacy of the basic control characteristics it should be borne in mind that the relatively light control forces, together with low windmilling drag of the propellers, are a contributory factor to the ease of handling under asymmetric power conditions.

8.4 Water Behaviour

8.4.1 Spray Characteristics

In the course of the trials, take-offs have been made at all-up weights of up to 315,000 lb and in up to 4 ft seas. Under the highest weight and roughest sea conditions some bending of the inboard propeller blades has occurred owing to the spray.

This/

This bending has in general been slight and within acceptable limits, but operations were normally restricted to relatively calm conditions. Tests were commenced on a propeller having strengthened tips, but flying was discontinued before any conclusive evidence of the effect of the stiffening could be determined, and this is discussed further in Reference 2.

Fine spray entered the inboard propeller discs and engine-air intakes during the initial part of the take-off run under all conditions. This only occurred over a small speed range, the duration being of course dependent on aircraft weight and the effect of this is discussed in Reference 2.

8.4.2 Take-Off Stability

No attempt was made to determine water stability limits as such, and no steady speed water runs were made. A series of take-offs was however made over a range of fixed elevator settings and all-up weights at a C.G. position of 29.5 per cent S.M.C. The handling aspects during these runs, and over the range of take-off conditions covered in the course of the tests is discussed in paragraph 7.2.

The range of elevator angles covered in the stick-fixed take-offs was from -3 to -11 degrees throughout the speed range and +10 degrees up to 60 knots. The hull attitude range covered was from 3 to 10 degrees between 30 and 80 knots water speed. All the measurements were made with a wing flap setting of 10 degrees down. The measurements of keel attitudes were plotted against all-up weight for various elevator angles and water speeds. In this way the effect of weight on attitude was determined, and, at the lowest water speeds considered, 30 and 40 knots, was negligible. At the higher speeds, 50 to 80 knots, the mean slope of the attitude versus weight curve at any elevator angle was 0.015 degrees per 1,000 lb. The measured attitudes were then grouped into low and high weight values, and, where appropriate, corrected to weights of 240,000 and 290,000 lb by this relationship, the corrections being made to the nearest 0.1 degree.

These corrected results were then plotted against elevator angle for water speeds of between 30 and 80 knots in 10 knot increments. From the lines through these points the attitudes have been plotted against water speed for elevator angles of -10, -5, 0 and +10 degrees for the two weights (Figure 18).

In this figure the firm lines correspond to conditions which have been covered by the operating conditions and at which no instability has been encountered, the dotted extension for zero elevator above 60 knots being derived by extrapolation. For both weights the effectiveness of the elevator is the same, a change of 12 degrees in elevator angle at the hump producing 1 degree change in keel attitude. Free to trim (η = 0) the effect of increase in weight is to increase the hump speed and attitude, (6 knots and 0.8 degrees respectively between 240,000 lb and 290,000 lb). At higher speeds the elevator is of course more effective requiring only about 4 degrees per degree of attitude at 80 knots, the effect of weight remaining sensibly constant.

These results whilst not being as complete as could be desired, do at least indicate an acceptable degree of water stability during take-off.

8.4.2 Landing Stability

The landing behaviour has been treated in the same manner as that of the take-offs in order to prepare the trim picture in Figure 19. No instability has been encountered with a C.G. position of 29.5 per cent S.M.C. over the range of measured stick fixed conditions, which were from

-4/

-4 to -15 degrees of elevator at high weights with wing flaps 45 degrees (fully down), -11 degrees with flaps 10 degrees down at high weights and flaps fully down at low weights. The hull attitude range covered was from 4 to 13 degrees at speeds between 30 and 80 knots.

At a corrected weight of 290,000 lb the elevator effectiveness is roughly constant, being about 6 degrees per degree of attitude. The effect of weight is considerably greater than in the take-off case, being 0.05 degrees per 1,000 lb at speeds down to 50 knots, increasing to 0.07 at 30 knots. This increase at low speeds is due to the more prolonged hump condition at the high weight. The effect of flap is to reduce the hull trim at any speed; in changing from 10 degrees to 45 degrees down at 290,000 lb the reduction is about 1 degree. For comparison with the landing case with 10 degrees flap at 290,000 lb the same case for the take-off with -10 degrees elevator angle has also been shown in Figure 19, giving a measure of the effect of power and acceleration on the attitude which at the hump reduce the trim by about 4 degrees. As for the take-off these results indicate acceptable water stability in the landing case.

9. CONCLUSIONS

The basic stability and controllability of the Princess about all axes in the air and on the water appears to be satisfactory over the range of envisaged loading and operation conditions. Whilst the water stability tests have been rather restricted in their scope, the indications are that over the range of conditions which have been covered (225,000 to 315,000 lb all-up weight, C.G. position 29 to 33 per cent S.M.C.) the stability during take-off and landing is acceptable.

With the existing propellers, it has been found desirable to restrict operations to relatively calm sea conditions, owing to the tendency for the propeller tips to be bent slightly due to the spray at high weights and in relatively rough water (4 ft sea). Modifications were made to the tips of one propeller, but the tests were discontinued before any effect of a modification could be determined. Under choppy conditions slight hull pounding was encountered on occasions.

Longitudinally, in the air, the limiting stability case is that of low speed, full power with flaps and floats retracted. This condition which is appropriate to initial climb away after unstick would determine an aft C.G. for positive stability of about 35 per cent S.M.C. with a 20 per cent flap setting for take-off. In cruising flight the aircraft would be positively stable with a C.G. position of 40 per cent S.M.C.

The power of the control surfaces with the accompanying small control movements required, gives rise to low control forces with the existing feel generator system. The nature of the control to control surface ratio masks the true stability characteristics, and in some cases the over-sensitivity produces impressions of instability at conditions where there is in fact an adequate degree of positive stability. Whilst this is unsatisfactory the solution is a mechanical rather than an aerodynamic one.

No assessment has been made of the handling with a half of any control surface inoperative, but the effectiveness of the full surface is such in all cases, that this behaviour should be satisfactory particularly as an emergency condition. It would in fact introduce a more positive feel of stability owing to the larger control movements required.

The/

The low speed flying behaviour is generally good there being adequate stall warning in the form of airframe buffeting. The minimum control speed for engine failure in the take-off configuration appears to coincide with the power off stalling speed, the low windmilling drag of the propeller on a two-shaft propeller turbine engine and the powered flying controls being important contributory factors to the ease of handling in this condition.

On the water, further development work to allow greater flexibility of engine and propeller operating conditions is required to improve the manoeuvrability.

10. ACKNOWLEDGEMENTS

Acknowledgements are made to Messrs. Saunders-Roe, Ltd., for preparing this report, which was written by Mr. G. F. Chalmers of the Flight Test Department, and Mr. G. A. V. Tyson, The Chief Test Pilot of that company.

LIST OF SYMBOLS

LIST OF SYMBOLS

C_R = Resultant force coefficient = $W/\frac{1}{2}\rho_o\ Vi^2 S$

W = Aircraft all up weight lb

ρ_o = Standard sea level density = 0.00238 slugs per cubic ft

S = Wing area sq ft

Vi = Equivalent air speed $V\sqrt{\sigma}$ - knots

V = True airspeed - knots (except for rolling requirement where V is in ft per second)

σ = Relative air density = ρ/ρ_o

T_c = Propeller thrust coefficient = Thrust per couple propeller/ $2.856^{+}\ \rho V^2 D^2$

D = Propeller diameter - ft

g = Acceleration due to gravity = 32.2 ft/sec^2

b = Wing span ft

ρ = Rate of roll - radians per second

K_N = Stick fixed static margin

η = Elevator angle - degrees

ξ = Aileron angle - degrees

ζ = Rudder angle - degrees

β = Angle of sideslip - degrees

$^{+}$2.856 is conversion from knots^2 to (ft/sec)^2

LIST OF REFERENCES/

LIST OF REFERENCES

No.	Author(s)	Title, etc.
1	-	M.A.E.E. Report No. F/186. Saunders-Roe Princess Flying Boat G-ALUN. Air and water performance tests. S.R. Report No. FT/15/0/24, Part 2. A.R.C. No. 17,831.
2	-	M.A.E.E. Report No. F/187. Saunders-Roe Princess Flying Boat G-ALUN. Engineering appraisal (Interim Summary). S.R. Report No. FT/15/0/24, Part 3. A.R.C. No. 17,883.

APPENDIX I/

APPENDIX I

Aerodynamic Data

Wing

Span, floats up	219.5 ft
Span, floats down	209.5 ft
Gross area, 5,118 sq ft including float, actual	5019 sq ft
Nett area, 4810 sq ft including float, actual	4711 sq ft
Aspect ratio 9.62 including float, actual	8.74
Aerofoil section, basic and root	Goldstein (developed)
Aerofoil section, tip	NACA 4415 (modified)
Standard mean chord	23.33 ft
Root chord	30.0 ft
Tip chord 12 ft 6 in. at wing/float junction; projected tip	11.0 ft
Thickness/chord ratio at tip (wing/float junction)	0.15
Thickness/chord ratio at root	0.18
Dihedral	0° 0'
Incidence to hull datum	4° 30'
Washout (wing tip only)	2° 0'

Flaps

Type	Slotted
Span, total	92.83 ft
Area, total	570 sq ft
Chord/local wing chord	0.212
Setting, fully down	45°

Ailerons

Type	Plain
Span, total	95.0 ft
Area, aft of hinge, total	300 sq ft
Chord/local wing chord	0.201

Ailerons (continued)/

APPENDIX I (Continued)

Ailerons

Angular movement, up and down	25°
TABS (One to each surface element - 8 in all)	
Type	Radius nose, sealed gap, geared
Span, total (4 per side)	37.95 ft
Area total	26.95 sq ft
Tab chord/control chord	0.201
Gearing	1:1

Tailplane and Elevators

Tailplane span	77.17 ft
Tailplane and elevator, gross area	1103 sq ft
Tailplane and elevator, nett area	1030 sq ft
Tailplane and elevator mean chord	14.33 ft
Tailplane aerofoil section	Goldstein (developed)
Root chord	22.08 ft
Tip chord	6.75 ft
Thickness/chord ratio at root	0.152
Thickness/chord ratio at tip	0.12
Dihedral	12°
Incidence to hull datum	2°
Elevator span, total	67.08 ft
Elevator area	259 sq ft
Elevator chord/local tailplane chord	0.275
Elevator angular movement	25° up, 20° down
Tail arm, from wing quarter mean chord point, to tailplane and elevator quarter mean chord	75.5 ft

ELEVATOR TABS (One to each surface element, 4 in all)

Type	Radius nose, sealed gap, geared
Span, total (2 per side)	33.34 ft
Area, total	26.82 sq ft
Tab chord/control chord	0.193
Gearing	1:1

Fin/

APPENDIX I (Continued)

Fin and Rudder

Height	31.5 ft
Gross total area	569 sq ft
Mean chord	18.08 ft
Aerofoil section	Goldstein (developed)
Root chord	25.5 ft
Tip chord	11.08 ft
Thickness/chord ratio at root	0.149
Thickness/chord ratio at tip	0.113
Rudder area, total	111 sq ft
Rudder span	23.25 ft
Rudder chord/local fin chord	0.2704
Rudder angular movement, port and starboard	30°

RUDDER TABS (fitted to lower element only)

Type	Radius nose, sealed gap, geared
Span	5.125 ft
Area	5.45 sq ft
Tab chord/control chord	0.181
Gearing	1:1

Hull

Length	148.0 ft
Gross area	7,325 sq ft
Total wetted area	6,912 sq ft
Maximum depth	24.25 ft

C.G. Datum

Horizontal (aft of forward perpendicular)	48.8 ft
Vertical (above hull bottom level)	3.88 ft

Floats

Length	10 ft 0 in.
Depth	5 ft 0 in.
Beam	4.33 ft

Engines/

APPENDIX I (Continued)

Engines

Type	Bristol Proteus
Mark	600 single, 610 coupled
Nominal ratings, sea level static:	
Maximum	10,000 c.r.p.m. 2,500 S.H.P. + 820 lb jet thrust
Maximum continuous	9,500 c.r.p.m. 2,050 S.H.P. + 700 lb jet thrust

Propellers

Type	De-Havilland 4/6000/6, single, 4 + 4/6000/6-7½ coupled
Diameter	16.5 ft
Reduction gear	0.0877 single, 0.084 coupled

Pitch settings (at 72 in. radius) -

	Single	Coupled	
		Front	Rear
Reverse	-31°	-	-
Superfine	-	-5½°	-6°
Fine	+23°	+10°	+9½°
Feathered	+83°	+82°	+81½°

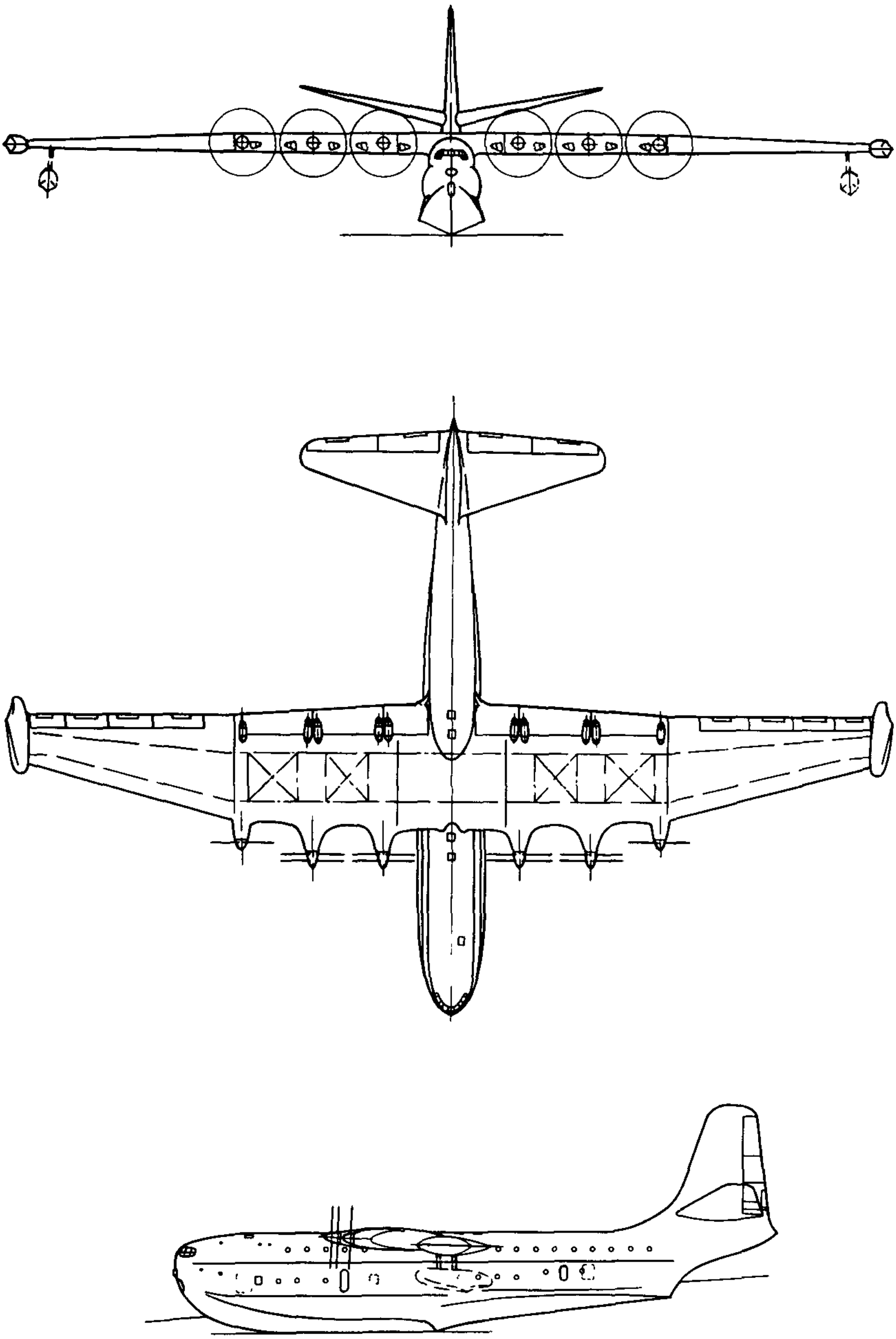
APPENDIX II/

APPENDIX II

Hydrodynamic Data

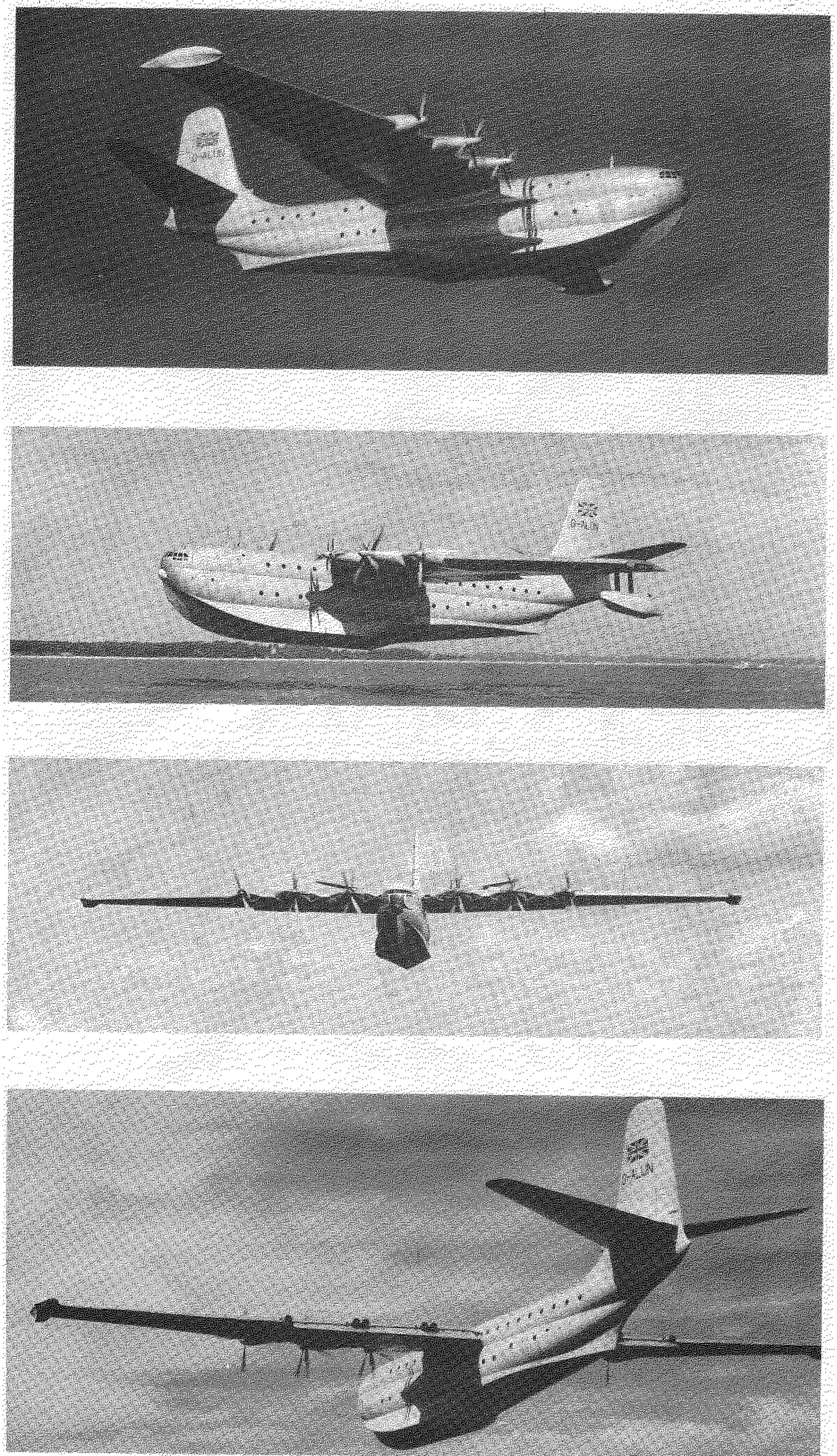
Forebody length	59.4 ft
Forebody chine deadrise (at step)	25°
Forebody keel deadrise (at step)	25°
Maximum beam (over chine)	16.67 ft
Afterbody length	61.4 ft
Afterbody deadrise	40°
Afterbody angle	7°
Sternpost angle	8°
Total planing bottom length/beam ratio	7.24
Forebody length/beam ratio	3.56
Afterbody length/forebody length	1.037
Step height (unfaired)	1.36 ft
Step fairing - elevation	6:1
Step fairing - plan form	2:1
Distance of C.G. datum forward of step	16.6 ft
Distance of C.G. datum above step	3.88 ft
Static draught at point of step All-up weight 315,000 lb	7 ft 10.63 in.

FIG. 1

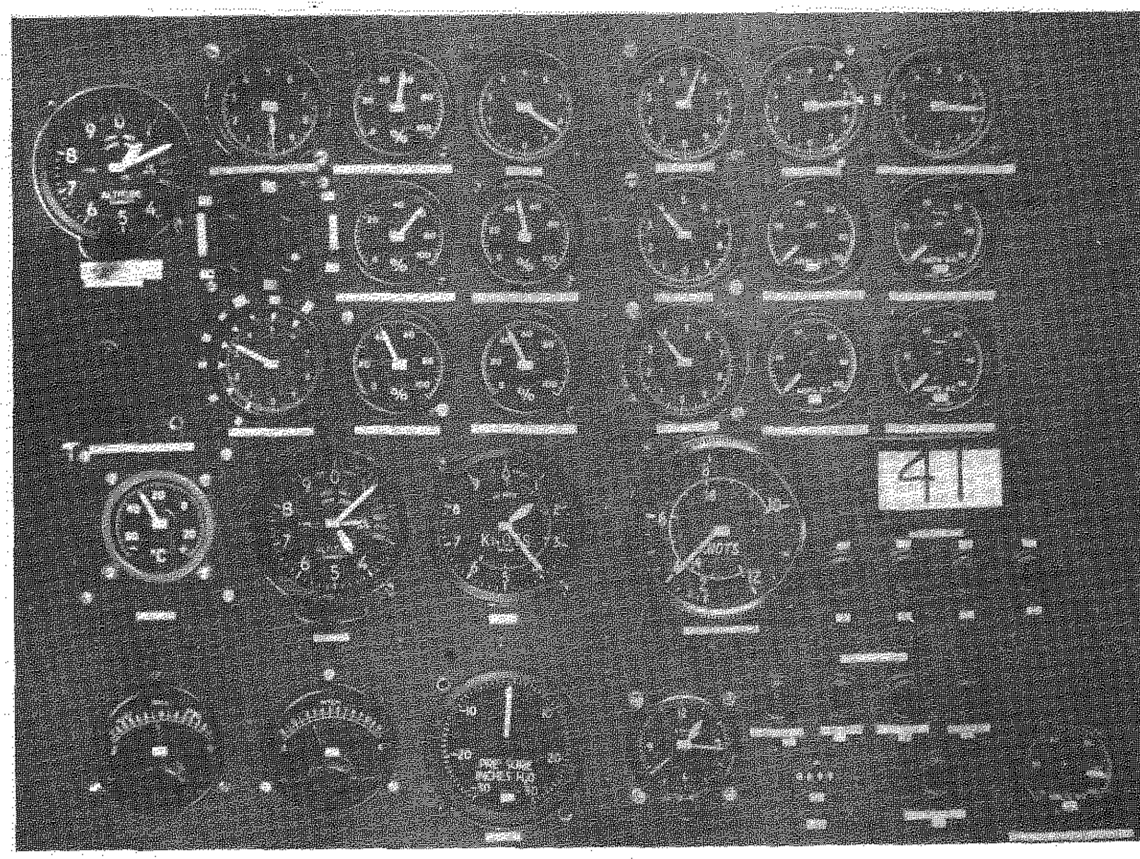


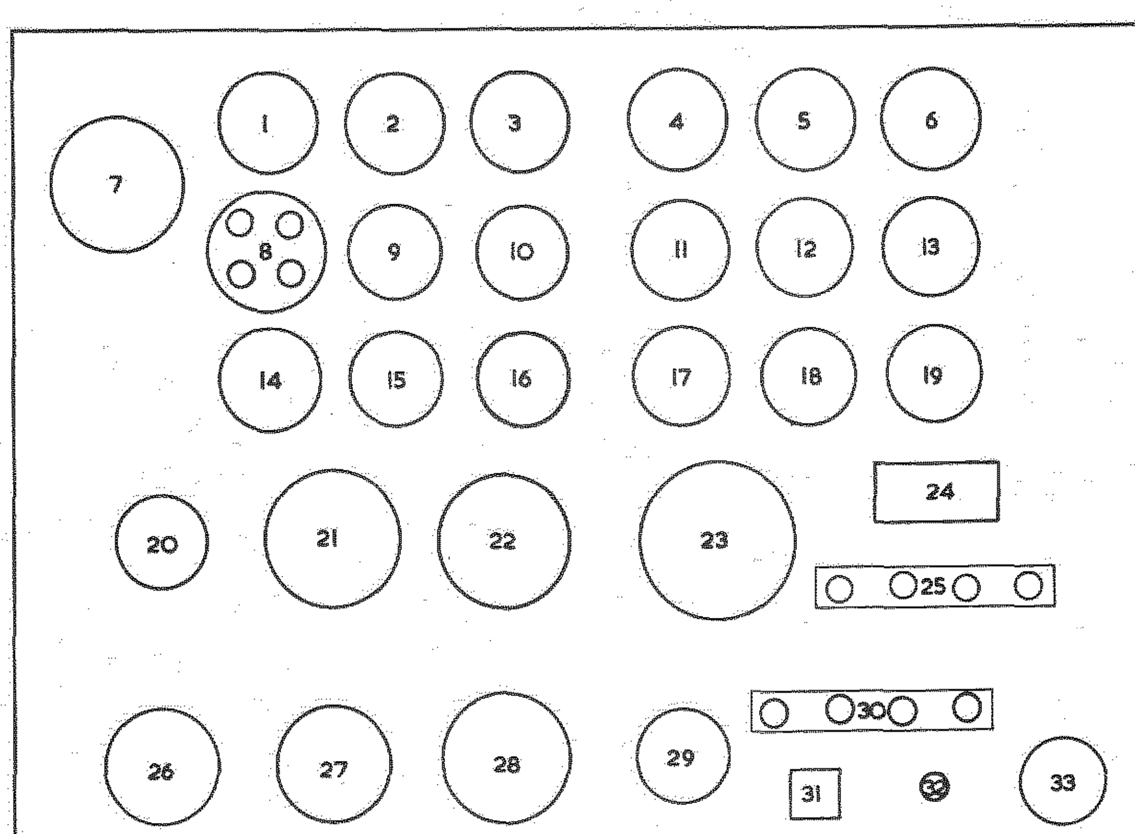
PRINCESS GENERAL ARRANGEMENT

FIG. No. 2



PRINCESS





1 LONGITUDINAL ACCELERATION
2 AILERON POSITION (PORT)
3 AIRCRAFT HEADING
4 RATE OF PITCH
5 WING FLAP POSITION
6 FLOAT AIR BOTTLE PRESSURE
7 CABIN PRESSURE
8 ATTITUDE AND BANK RANGE LIGHTS
9 AILERON POSITION (STBD)
10 ELEVATOR POSITION (PORT OUTER)
11 RATE OF YAW
12 WING FLAP (PORT) MOTOR CURRENT
13 FLOAT (PORT) MOTOR CURRENT
14 NORMAL ACCELERATION
15 RUDDER POSITION
16 ELEVATOR POSITION (PORT INNER)
17 RATE OF ROLL
18 WING FLAP (STBD) MOTOR CURRENT
19 FLOAT (STBD) MOTOR CURRENT
20 OUTSIDE AIR TEMP.
21 ALTITUDE
22 AIRSPEED
23 AIRSPEED (LOW RDG)
24 FLIGHT IDENT.
25 EVENT LIGHTS
26 BANK ANGLE
27 ATTITUDE ANGLE
28 SIDESLIP
29 TIME
30 FLOAT POSITION LIGHTS
31 1/2 SECOND COUNTER
32 WATER CONTACT LIGHT
33 BUS-BAR VOLTAGE

HANDLING AUTO-OBSERVER PANEL

ELEVATOR RESPONSE CURVES.

ELEVATOR ANGLE — STICK ANGLE, FOR ORIGINAL AND MODIFIED SYSTEMS.

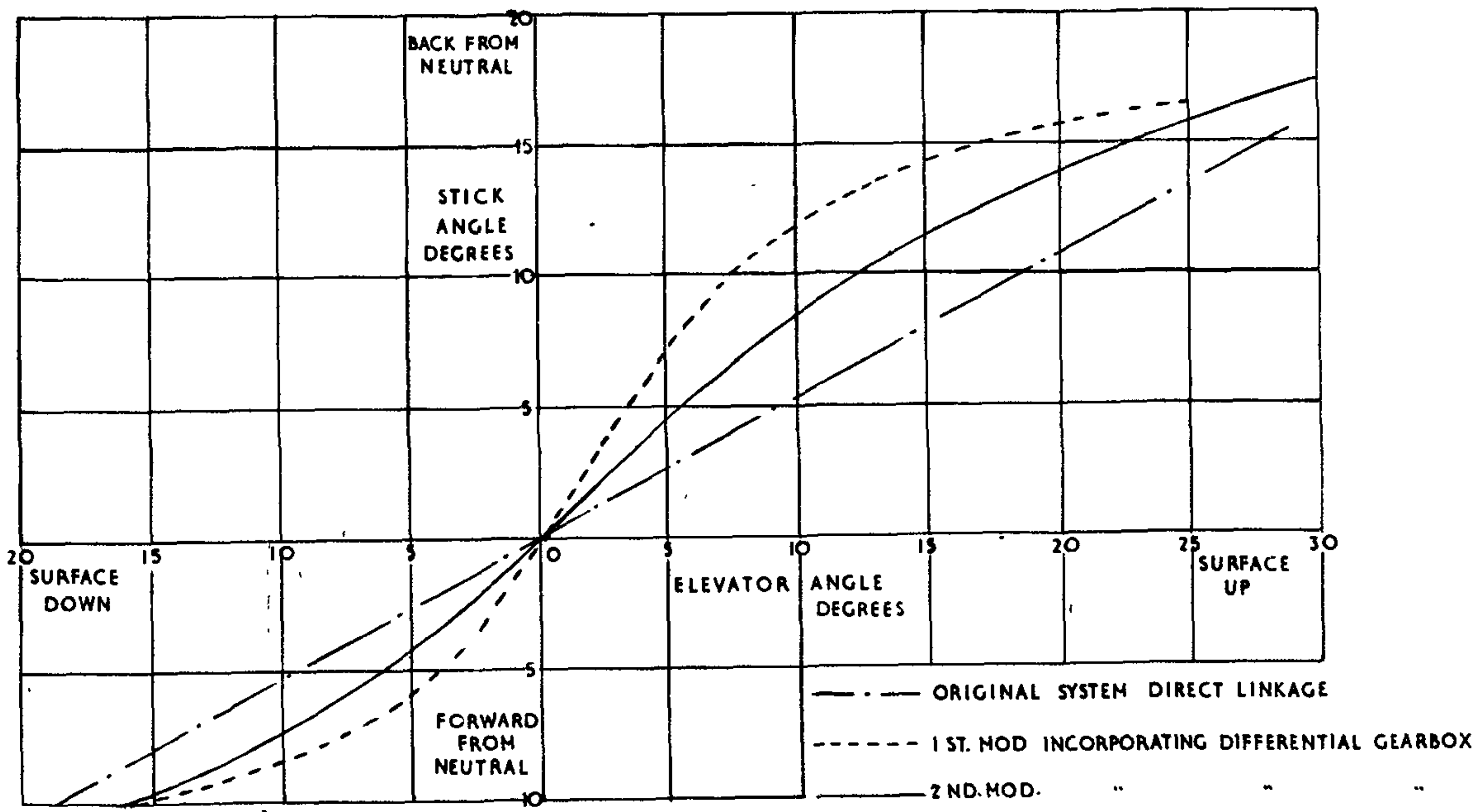
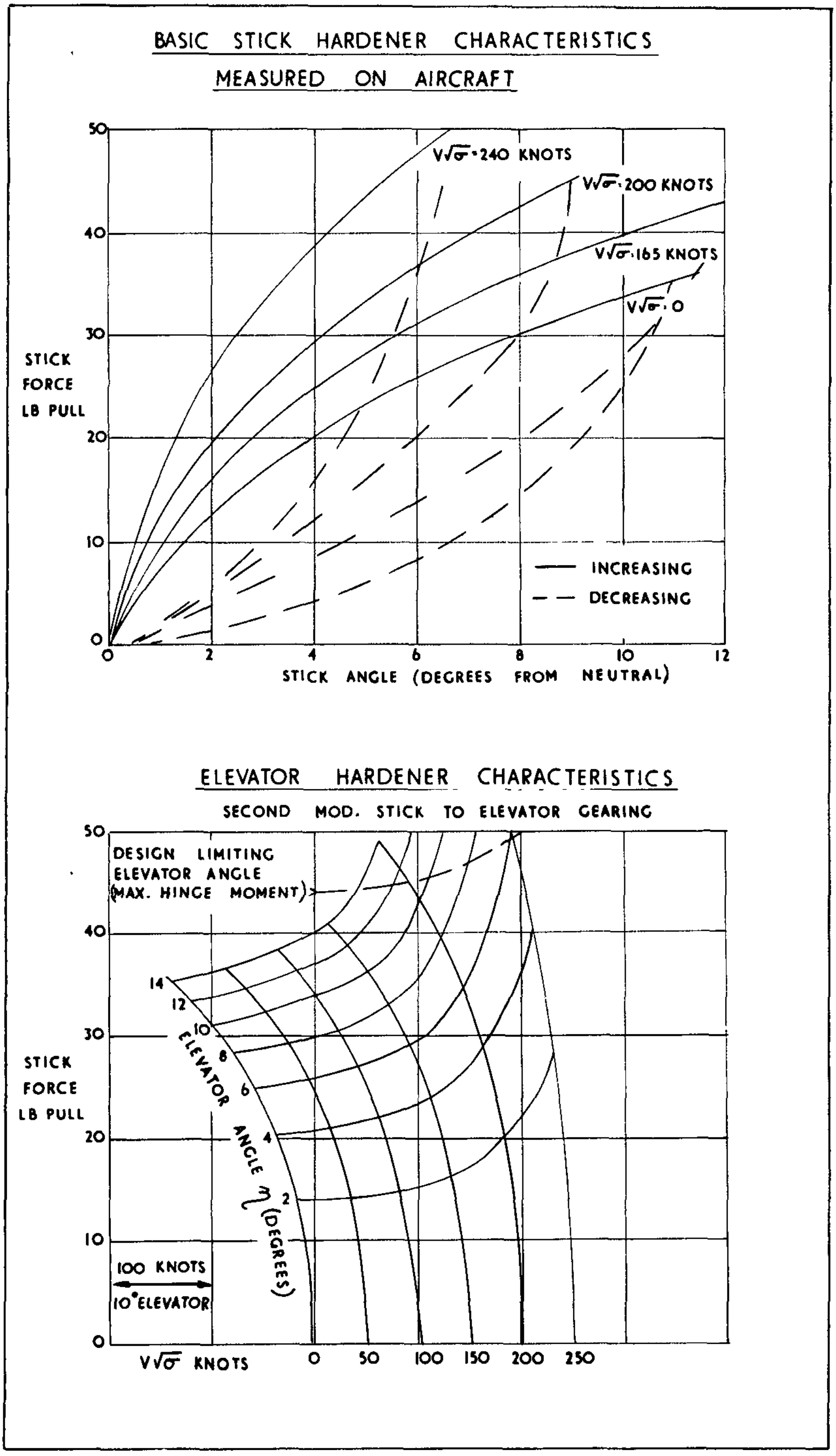


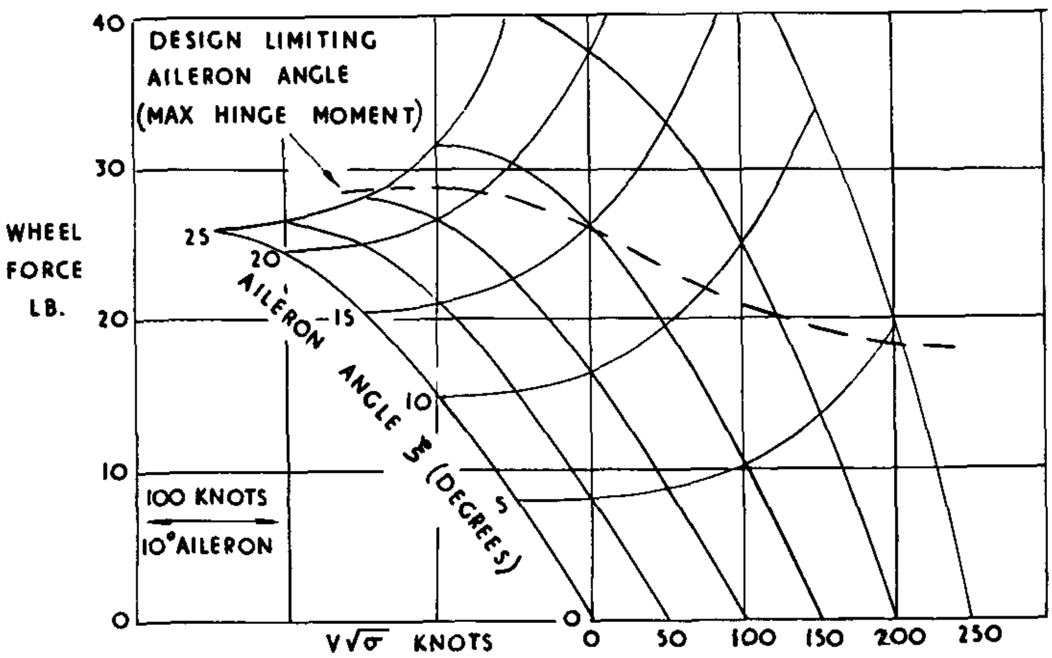
FIG. No. 4



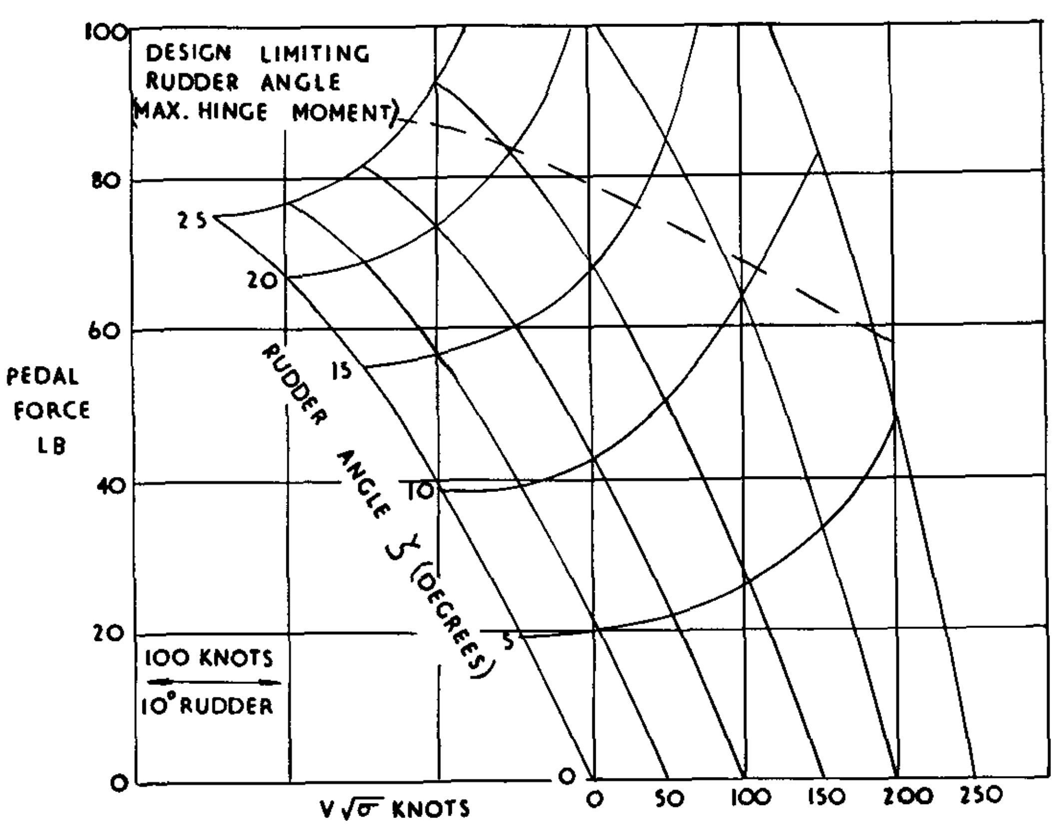
ELEVATOR LOAD CURVES

FIG. No. 6

AILERON HARDENER CHARACTERISTICS



RUDDER HARDENER CHARACTERISTICS



AILERON AND RUDDER LOAD CURVES

ELEVATOR TRIM CURVES
(FLAPS AND FLOATS RETRACTED)

$\eta - C_R$

FLAPS AND FLOATS RETRACTED. MEAN ALL UP WEIGHT 250,000 LB.

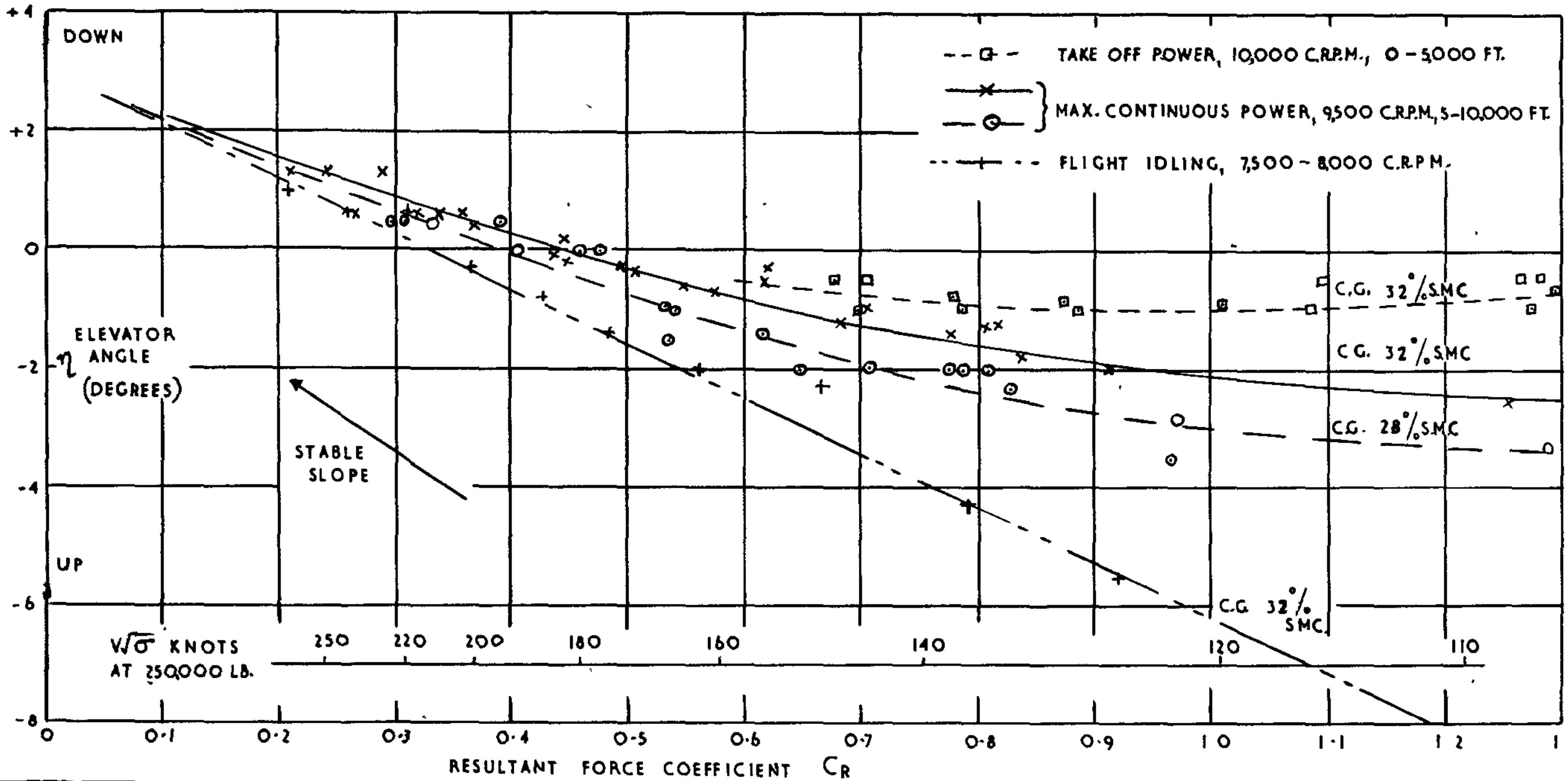


FIG. No 7

ELEVATOR ANGLE TO TRIM
(FLAPS AND FLOATS EXTENDED)

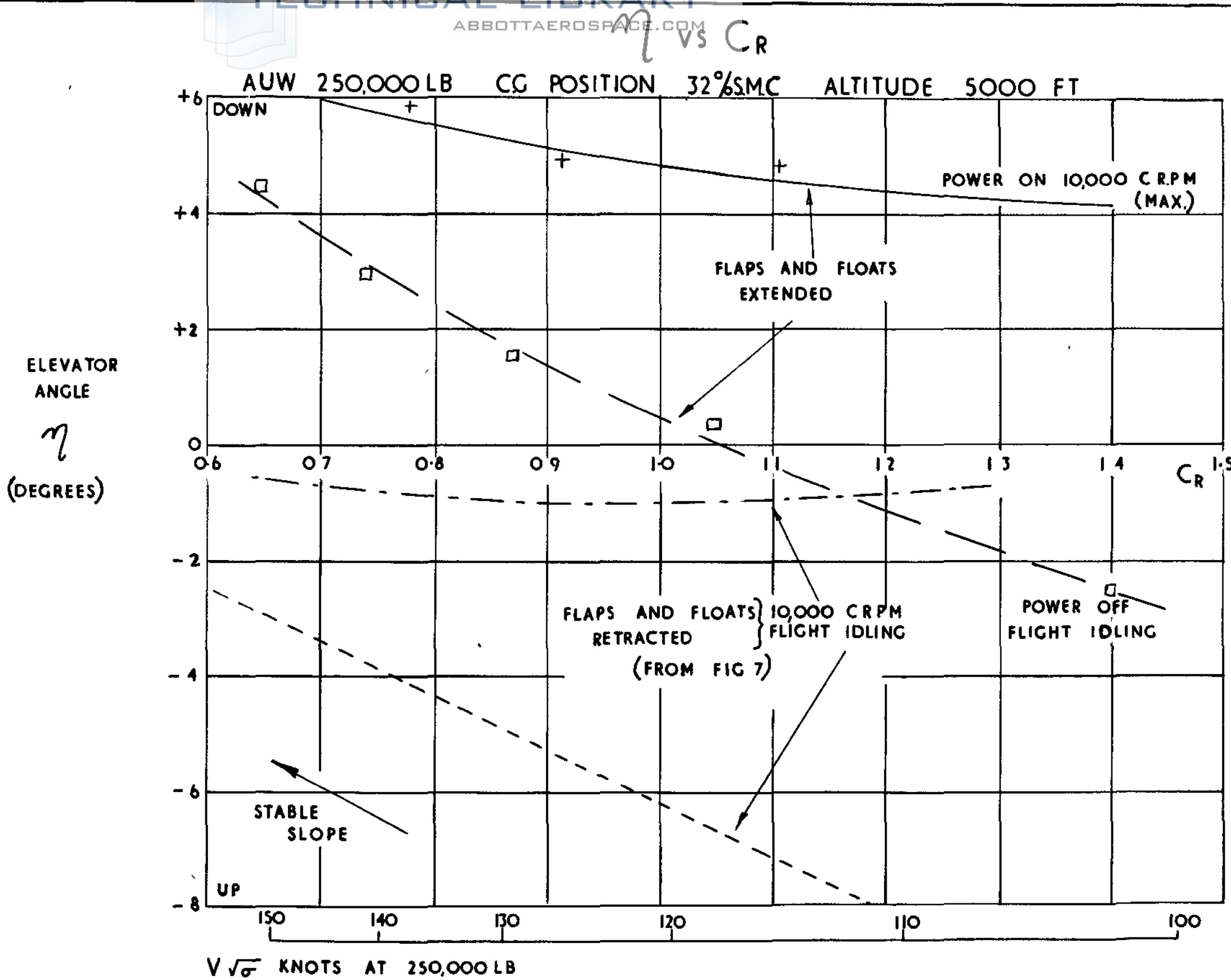
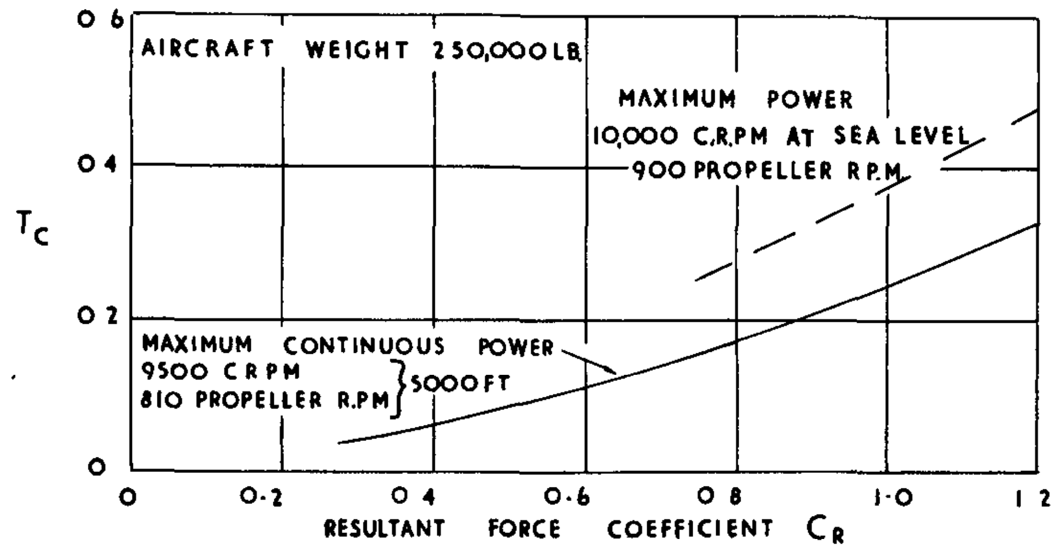


FIG. No.8

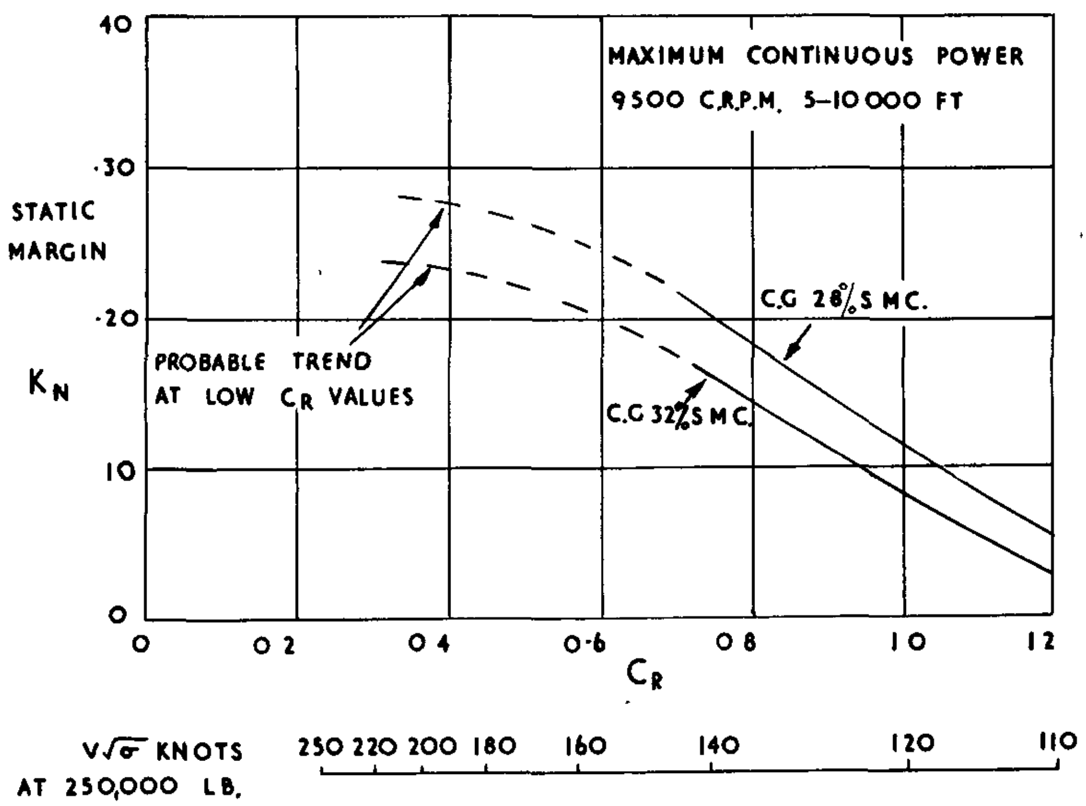
PROPELLER THRUST COEFFICIENT (Tc)

PER COUPLED UNIT



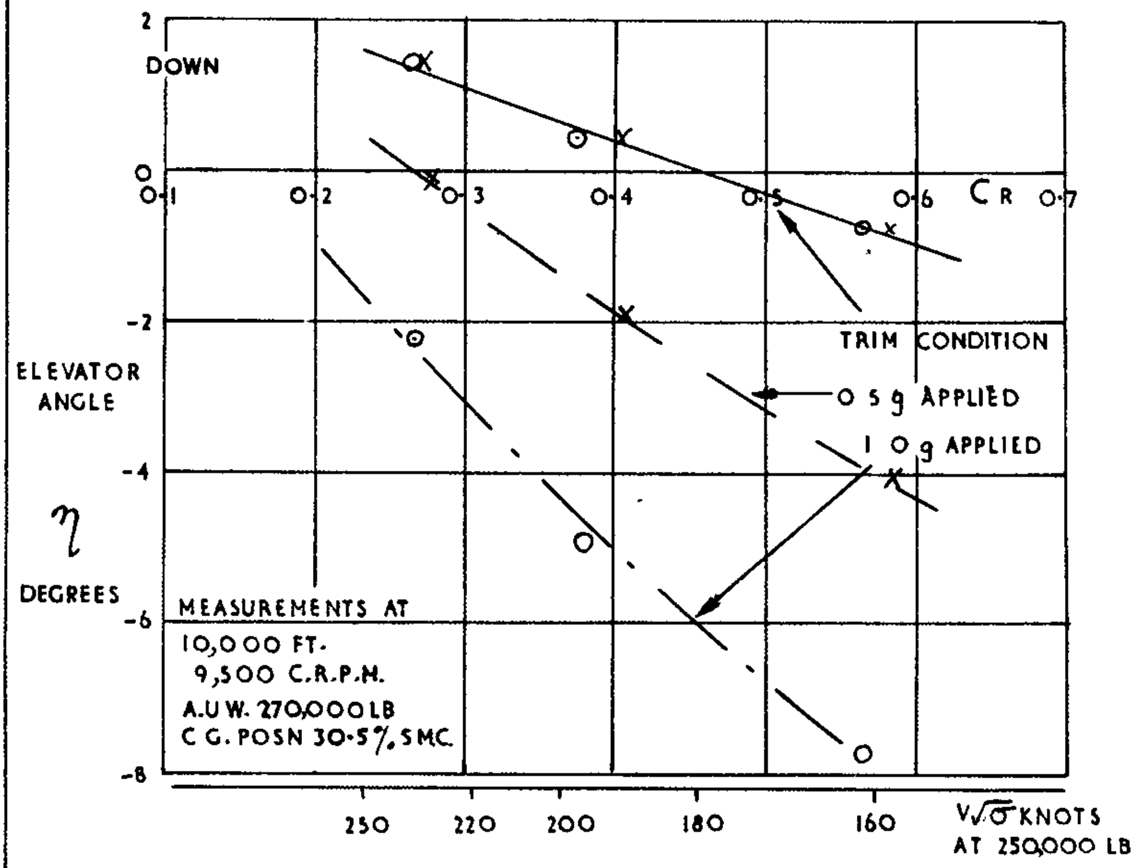
STATIC STABILITY MARGIN (STICK FIXED)

FLAPS AND FLOATS RETRACTED

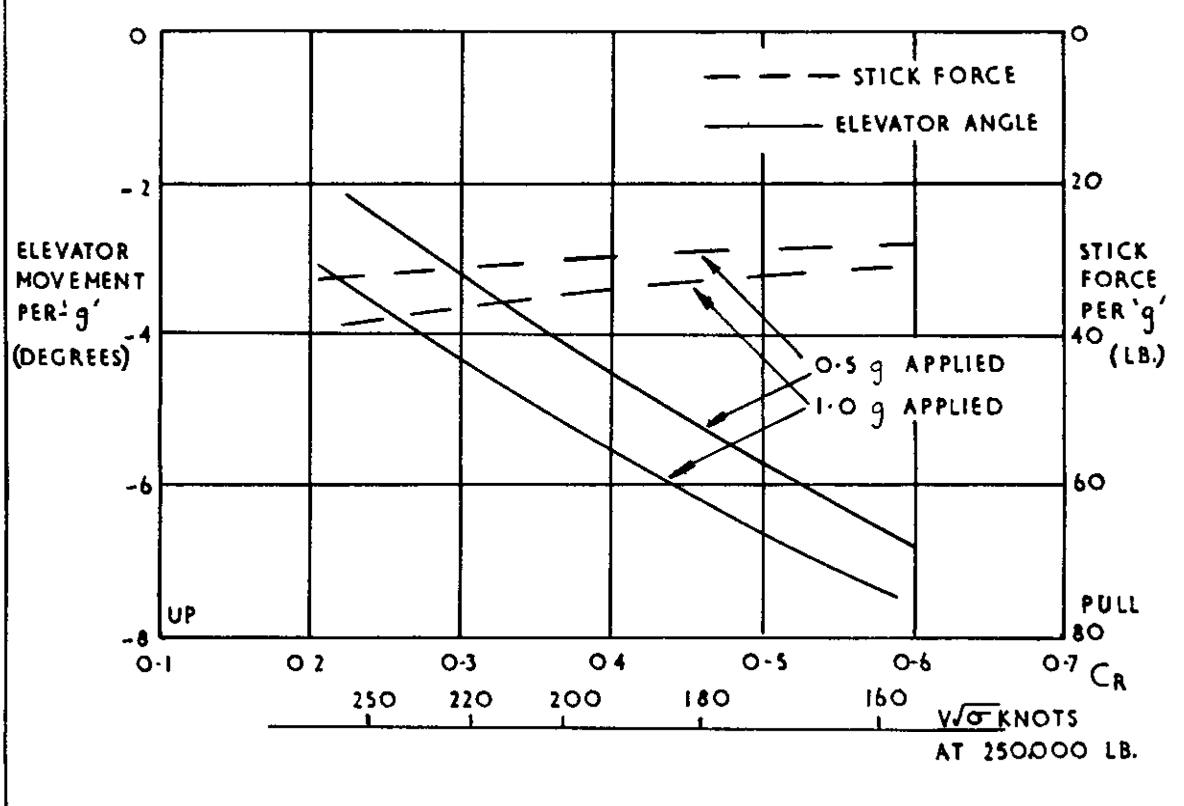


STATIC STABILITY MARGIN

ELEVATOR ANGLES TO TRIM AND TO APPLY 0·5 AND 1·0 'g'



ELEVATOR MOVEMENT AND STICK FORCE PER 'g'
(STICK FORCE FOR 2ND. MODIFIED STICK/ELEVATOR GEARING)



LONGITUDINAL MANOEUVRABILITY

LONGITUDINAL OSCILLATIONS

BEHAVIOUR SUBSEQUENT TO SHARP ELEVATOR DEFLECTION

ALTITUDE 30,000 FT C.R.P.M 9500 A.U.W. 240,000 LB. C.G. POSITION 29·2 % SMC

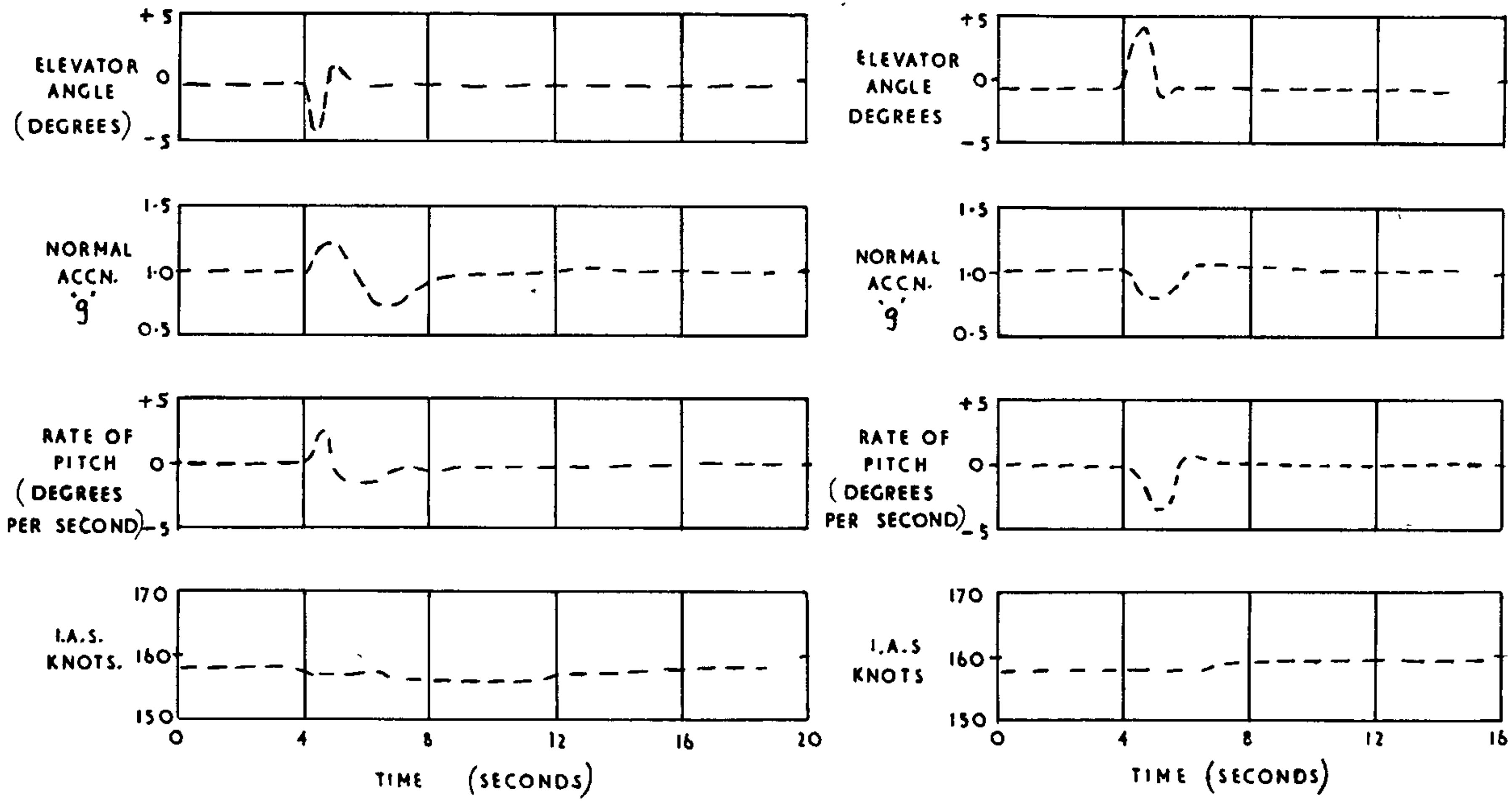


FIG. No. 11

VARIATION OF ROLL WITH AILERON ANGLE AND AIRSPEED

ALTITUDE 3,000–10,000 FT AUW 260,000 LB. C.G. POSN. 31·5% S.M.C POWER 9,500 C.R.P.M

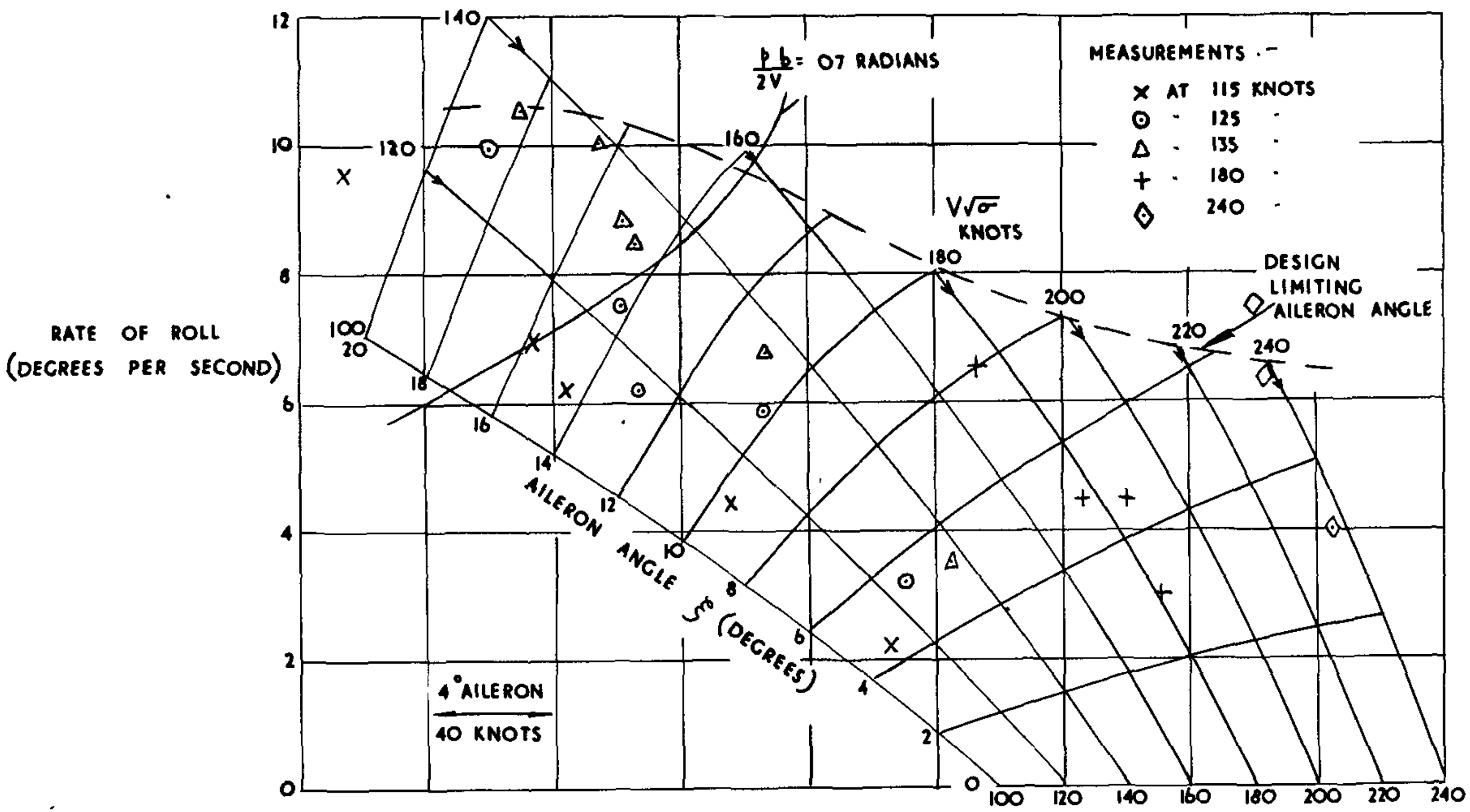
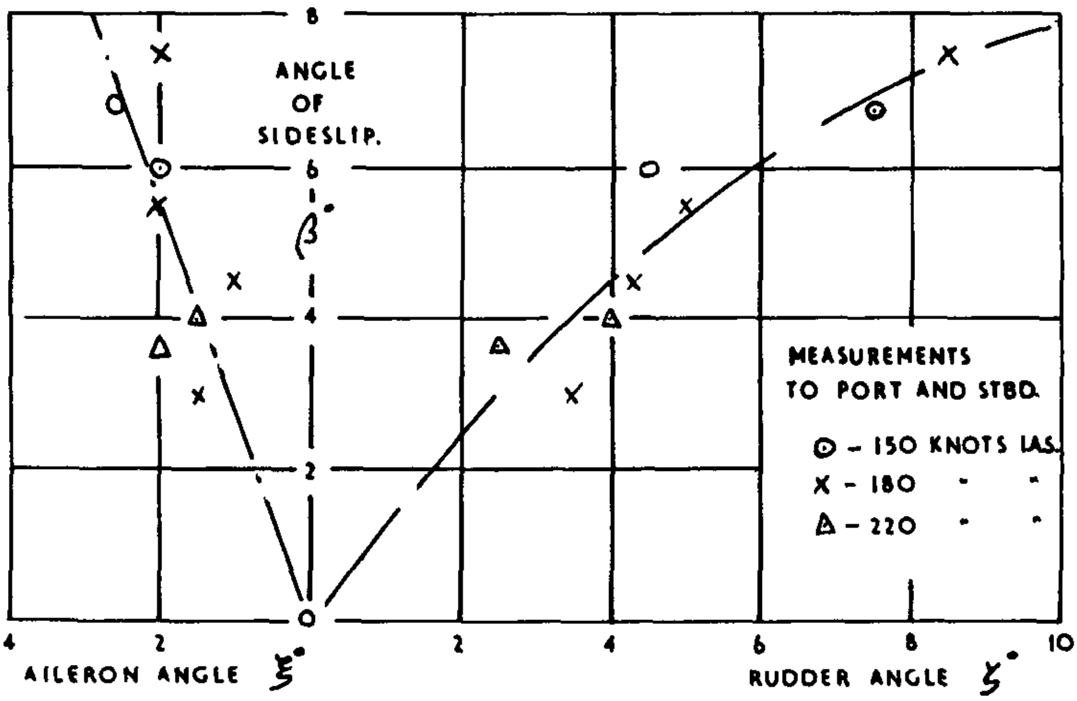


FIG. No. 12

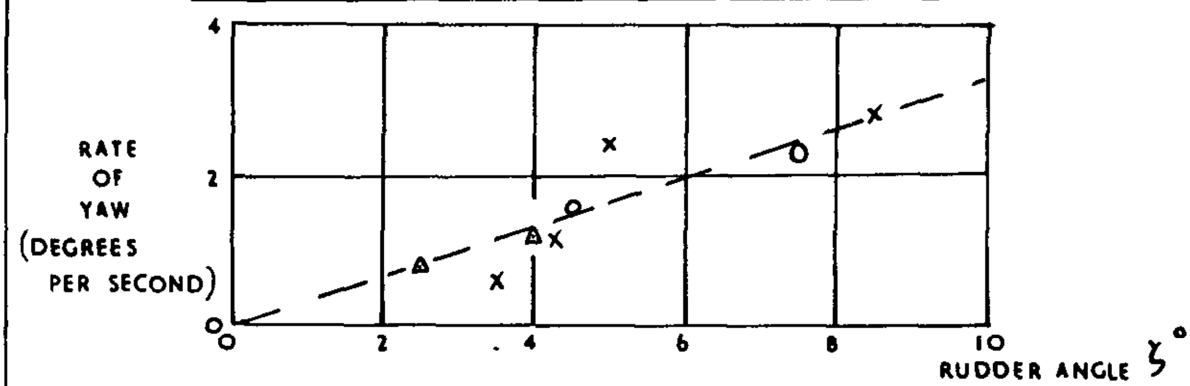
FIG No. 13

ALTITUDE 5000 FT. A.U.W. 260,000 LB. C.G. POSN. 31.5 % S.M.C.

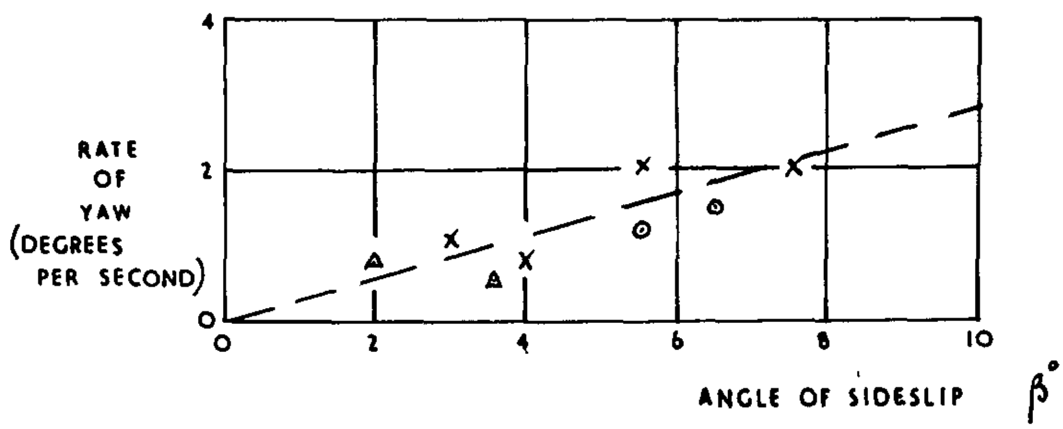
RUDDER AND AILERON ANGLES TO MAINTAIN STEADY SIDESLIP



MAXIMUM RATE OF YAW ATTAINED — RUDDER ANGLE

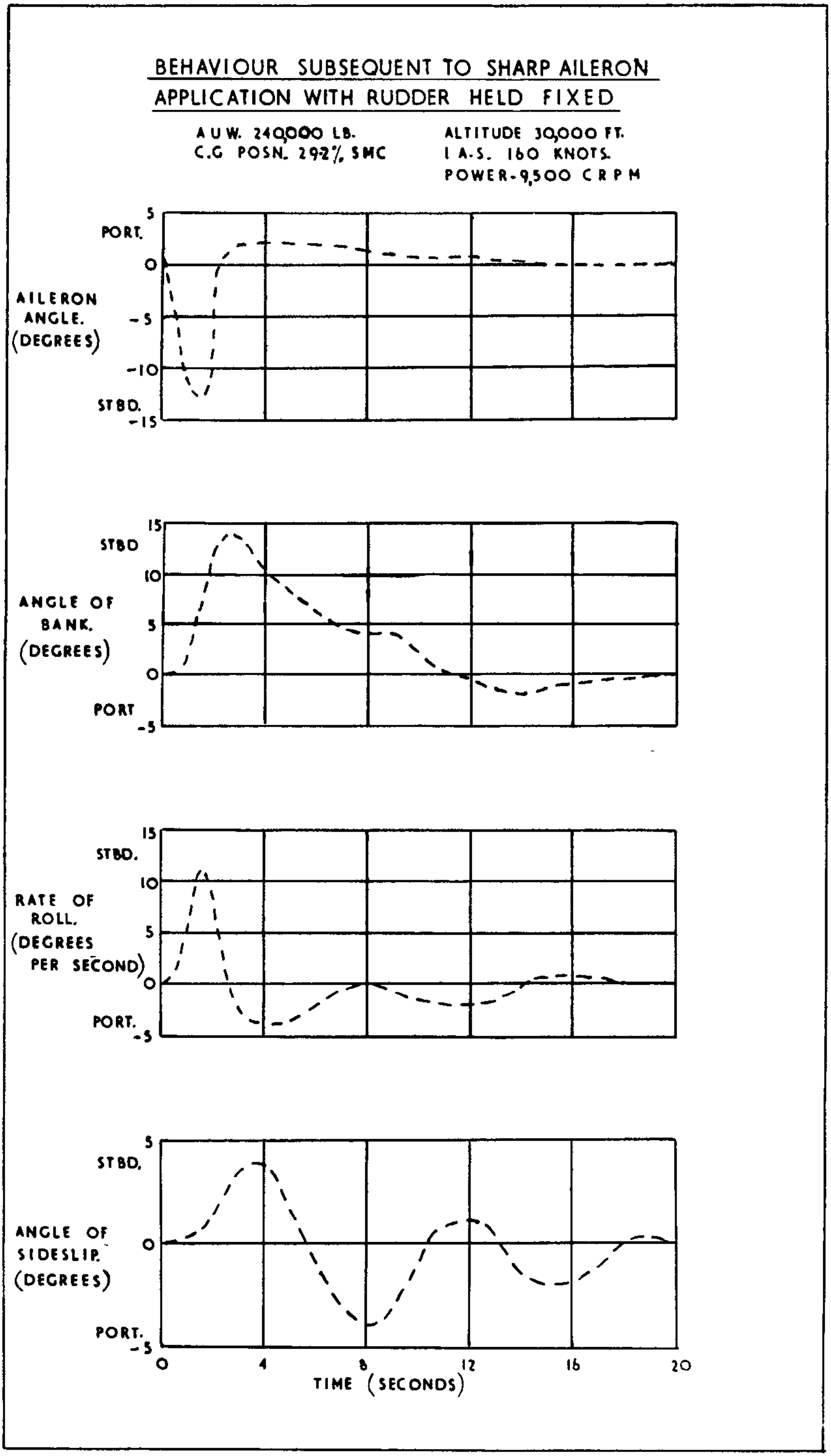


MAXIMUM RESTORING RATE OF YAW — SIDESLIP



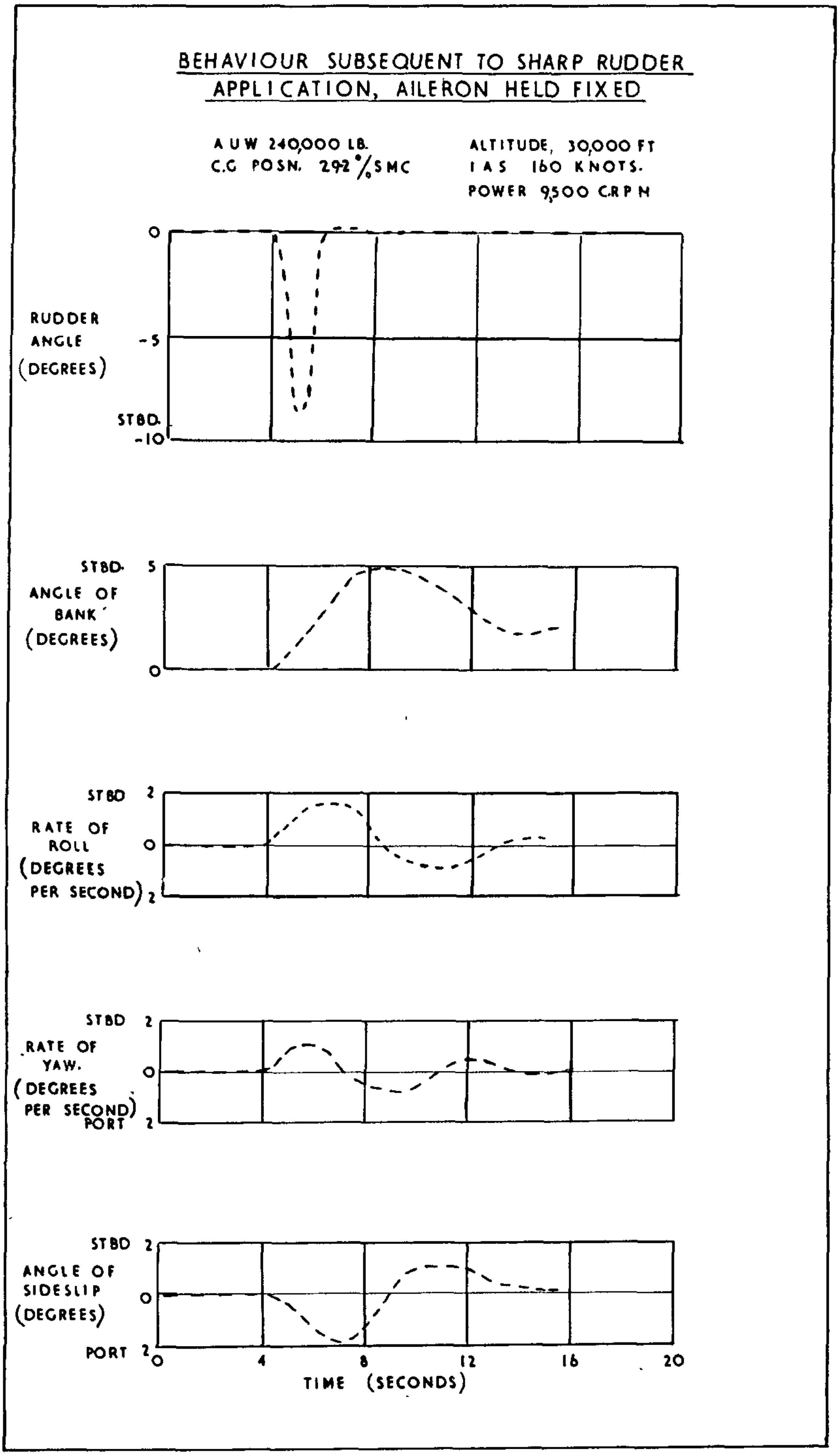
SIDESLIPPING.

FIG. No. 14



LATERAL OSCILLATION

FIG. No. 15

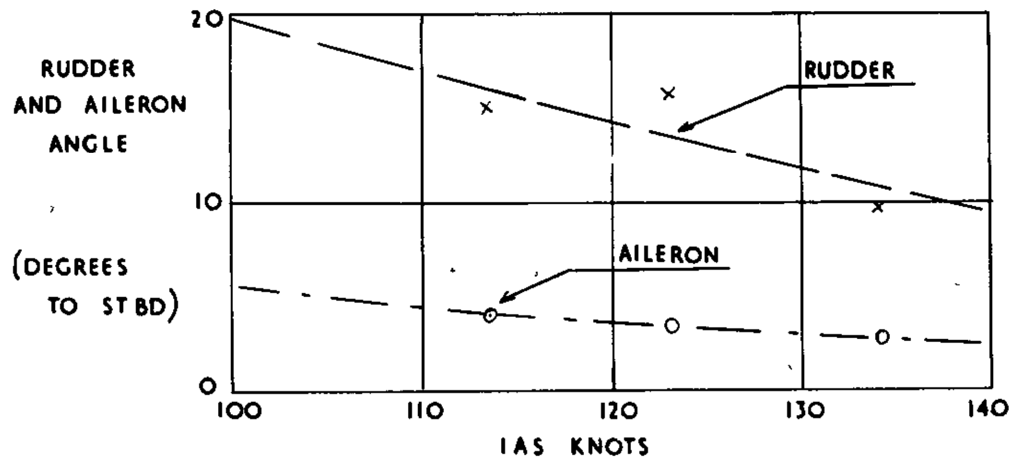


DIRECTIONAL OSCILLATION

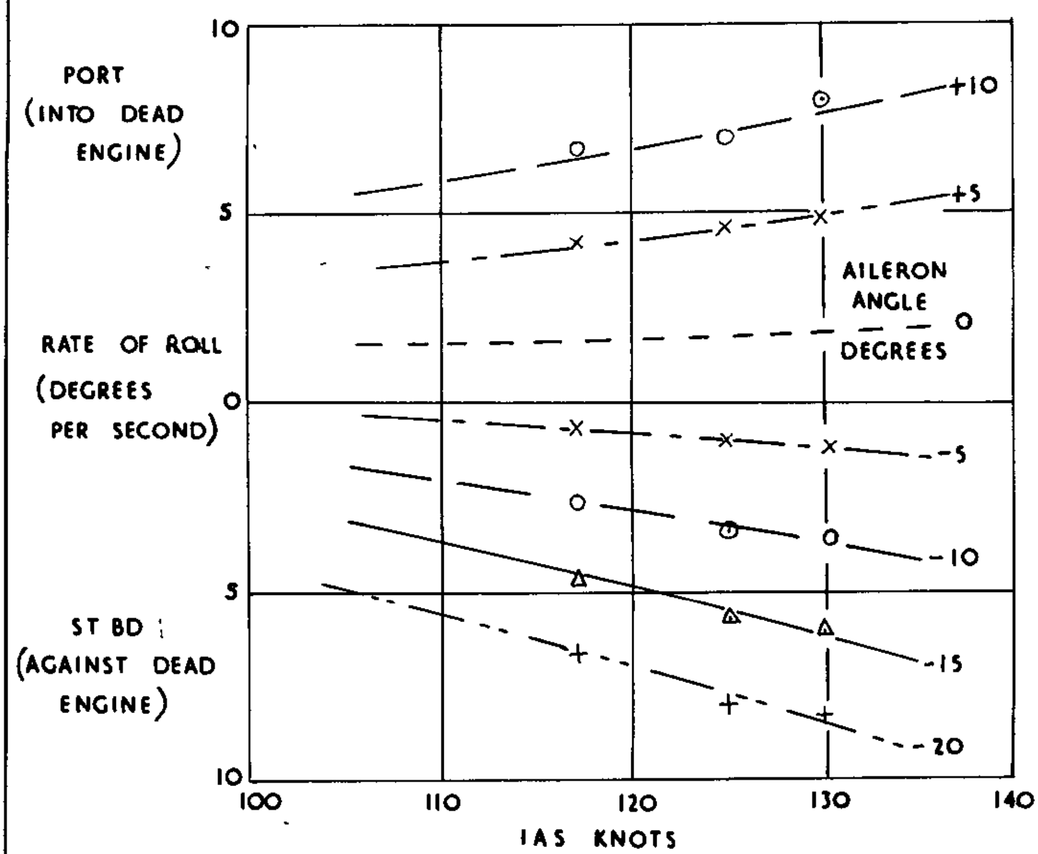
FIG. No. 16

AUW 280,000 LB. CG POSITION 29.5% SMC.

RUDDER AND AILERON ANGLES TO MAINTAIN STEADY STRAIGHT FLIGHT WITH WINGS LEVEL

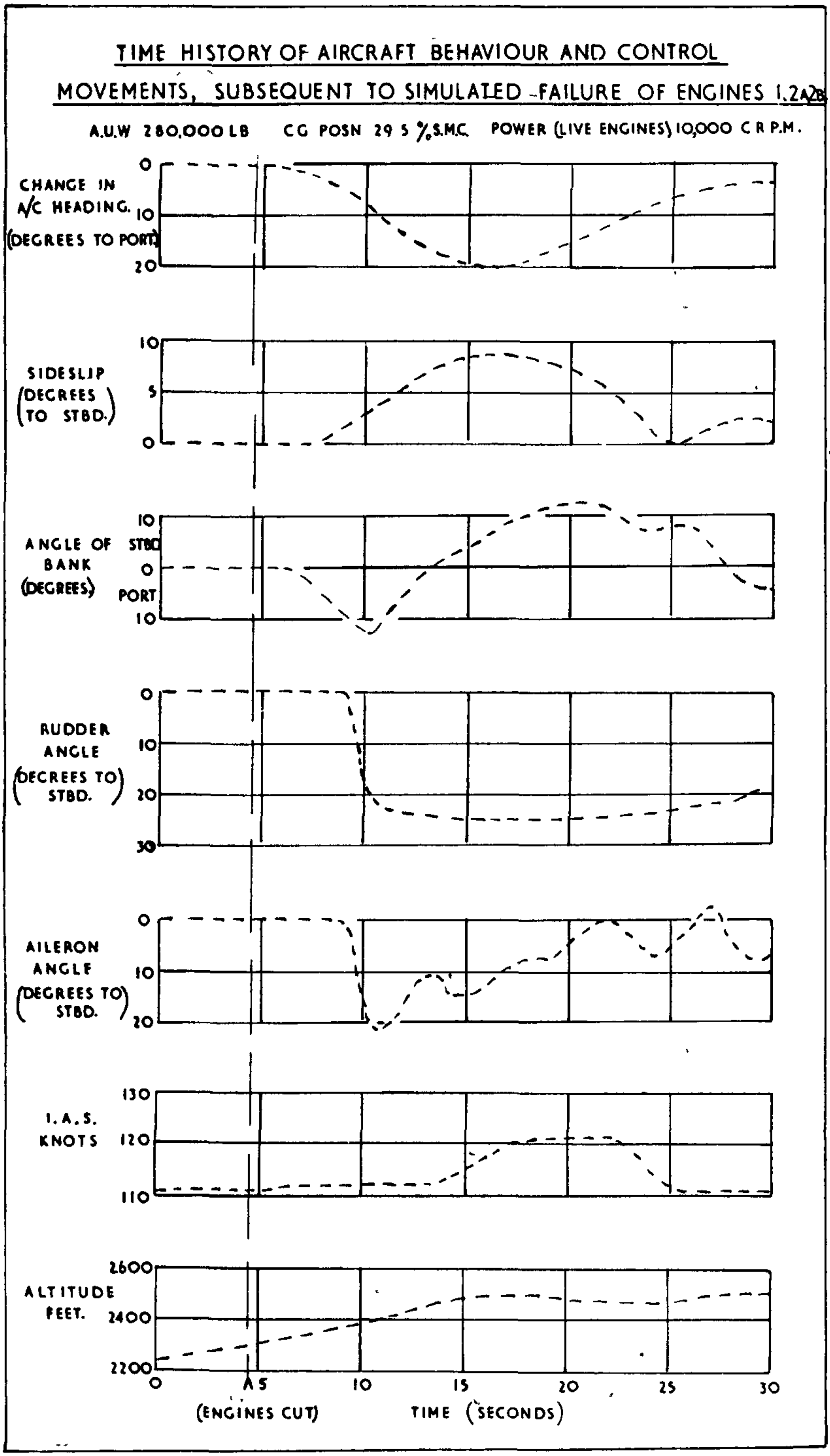


RATES OF ROLL INTO AND AGAINST DEAD ENGINE



ALTITUDE 2,500 FT
POWER No 1 OFF, 2A & 2B, 8400 CRPM
REMAINDER AT MAX.-10,000 CRPM

CONTROL WITH ASYMMETRIC POWER

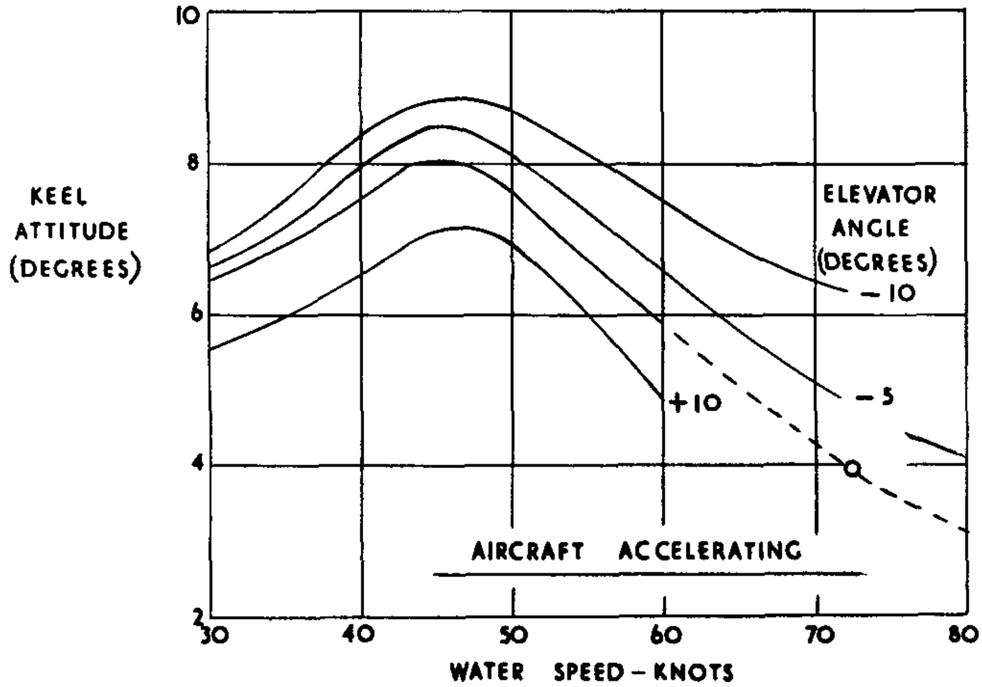


SIMULATED ENGINE FAILURE.

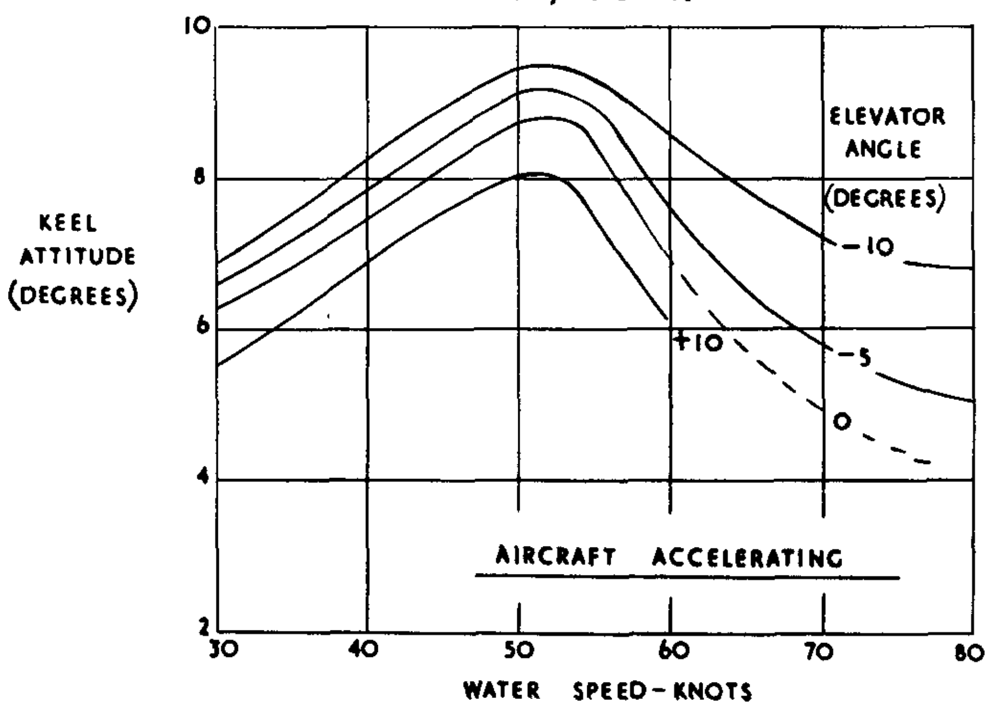
KEEL ATTITUDE – WATER SPEED

FLAPS 10° DOWN   C.G POSITION 29·5% S.M.C.

240,000 LB



290,000 LB.



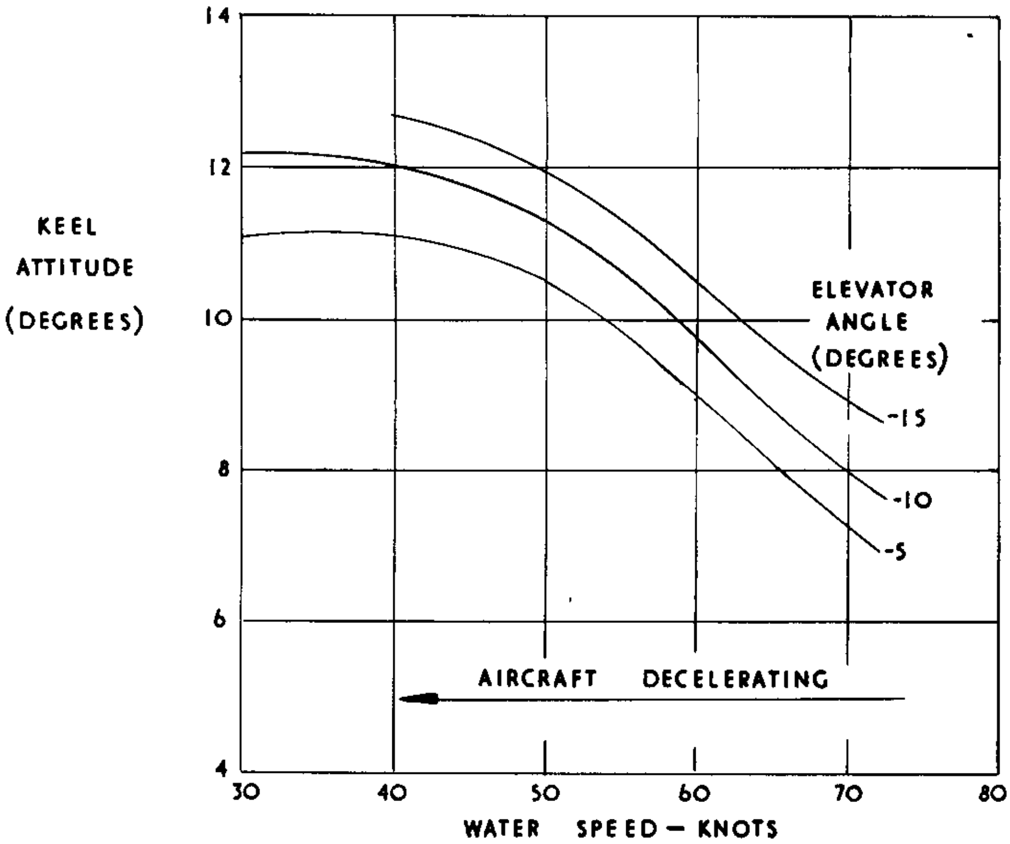
TAKE-OFF POWER – 10,000 C R P M.

HULL TRIMS DURING TAKE-OFF

KEEL ATTITUDE — WATER SPEED

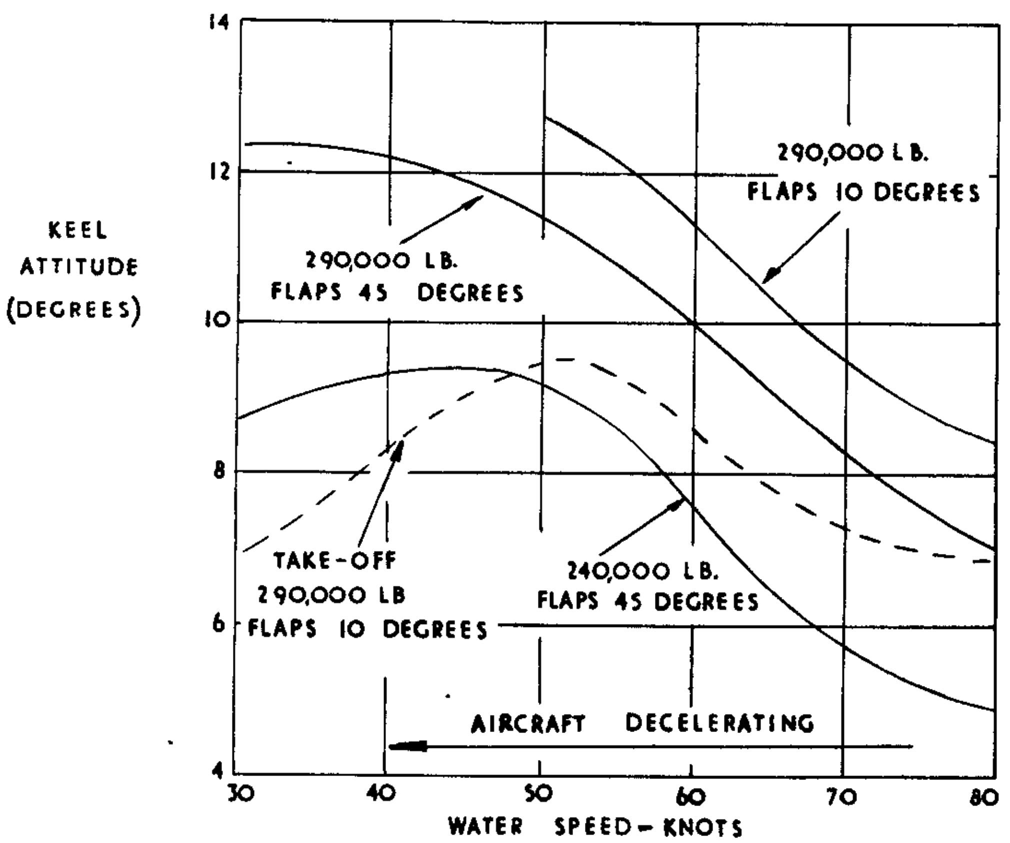
C.G. POSITION 29·5% SMC

290,000 LB FLAPS 45 DEGREES



EFFECT OF WEIGHT AND FLAP SETTING

ELEVATOR ANGLE — 11 DEGREES



FLIGHT IDLING POWER - 7000 C R.P.M.

HULL TRIMS DURING LANDING

C.P. No. 257
(17,859)
A.R.C. Technical Report

Printed and published by
HER MAJESTY'S STATIONERY OFFICE
To be purchased from
York House, Kingsway, London W.C.2
423 Oxford Street, London W.1
P.O. Box 569, London S.E.1
13A Castle Street, Edinburgh 2
109 St. Mary Street, Cardiff
39 King Street, Manchester 2
Tower Lane, Bristol 1
2 Edmund Street, Birmingham 3
80 Chichester Street, Belfast
or through any bookseller

Printed in Great Britain

S O. Code No. 23-9009-57

C.P. No. 257